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LOCKALLOY BE-38AL MATERIAL CHARACTERIZATION, 1976 YEAR-END REPO--ETC(U)
MAY 77 J F SULLIVAN, A C HARAMIS

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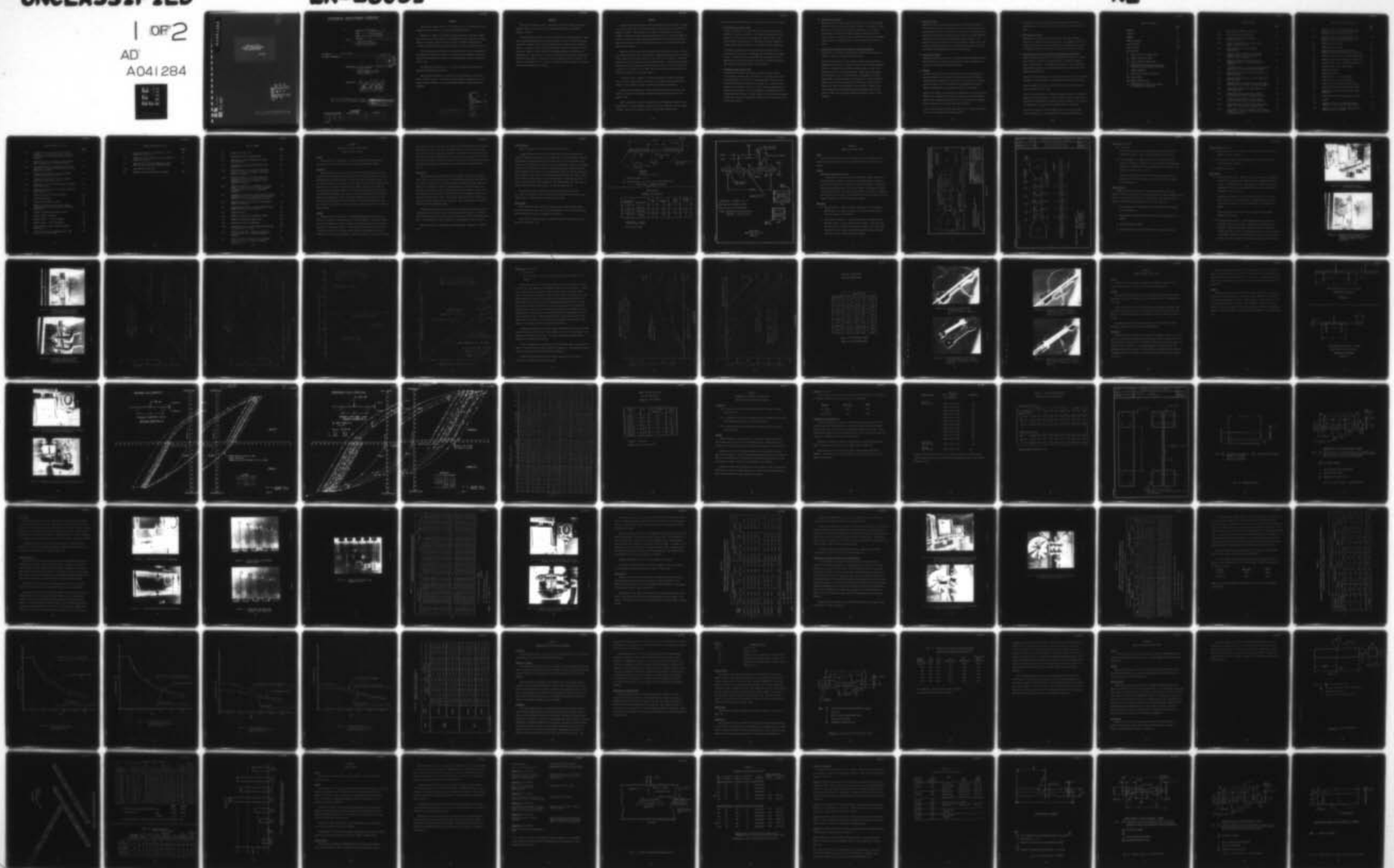

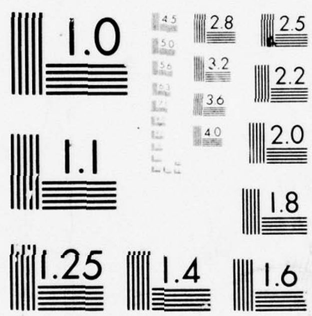

MICROCOPY RESOLUTION TEST CHART
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LOCKALLOY Be-38Al
MATERIAL CHARACTERIZATION
1976 YEAR-END REPORT

LR-28051

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FORM 402-2

FOREWORD

This year end report documents the results to date of a program to further establish the characteristics of Lockalloy (Be-38Al) material.

Lockalloy, Be-38Al, is a beryllium-aluminum composite material originally developed by LMSC. The potential use of Lockalloy as a structural material is emphasized for applications on Hypersonic Flight Vehicles or other installations requiring high stiffness to weight ratios, high heat conductivity and/or high specific heat.

The first major use of Lockalloy was established from the joint NASA/USAF YF-12 Lockalloy Ventral Fin Project, performed by ADP at Lockheed. Easy formability and machinability of Lockalloy were demonstrated during the fabrication of this fin.

The application of Lockalloy is considered by NASA and the USAF for the proposed X-24C Hypersonic airplane.

The interest and potential developed in the study phase of the X-24C together with the results of the YF-12 Ventral Fin work has warranted this independent study by Lockheed to provide additional material characterization of Lockalloy.

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ABSTRACT

This year-end report documents the results to date of a testing program to further establish the characteristics of Lockalloy material, a beryllium - aluminum composite.

The testing was performed by Advanced Design Projects (ADP) personnel. These tests involved experimental and analytical studies conducted to obtain additional information regarding basic Be-38Al Lockalloy material properties and characteristics. The studies provide data regarding impact strength, resistance to stress corrosion, response to post-manufacturing thermal treatment, weldability, and inspectability. The accuracy of methods for determining the modulus of elasticity and predicting compression instability (column strength) were also verified. In addition, the behavior of this material in certain structural concepts, considered for the X-24C airplane was evaluated.

SUMMARY

Lockheed Aircraft Corporation, Advanced Development Projects (ADP) is engaged in an independent funded test program to further establish the characteristics of Lockalloy material. This material is a composite of beryllium and aluminum, Be-38Al, developed by Lockheed Missiles and Space Division. This test program was intended to provide Lockalloy material characterization over and above the information resulting from the YF-12 Lockalloy Ventral Fin Program and previous Lockalloy testing programs.

Hypersonic vehicles are subject to predictable aerodynamic heating. Stresses due to temperature gradients and differences in expansion coefficients in dissimilar metal assemblies are of major concern in the design of such vehicles. Structural analysis will account for all calculated thermal stresses. There will be, however, instances where the temperature and the resulting stresses do not lend themselves to prediction or analysis. Heat leaks, interference heating, and localizing secondary deformations are a few such examples.

A material which is capable of withstanding repeated straining excursions into the plastic range would be very forgiving to unforseen over-straining and therefore very desirable for high temperature structural applications.

As part of this IRAD effort three non-standard tests were devised and performed to evaluate the tolerance of Lockalloy to repeated straining into the plastic range.

Other investigations into the characteristics of Lockalloy included in this program were: buckling allowable predictions, thermal treatment response, impact strength, electron beam welding, stress corrosion, NDT inspectability.

A summary of the testing performed and the results obtained follows below.

1. <u>Cyclic Bending - Plastic Hinge</u>

   Strips of Lockalloy, .250 inch thick, were subjected to end moments @ 600°F, to induce end rotations. The strips were repeatedly cycled between 0 and 6° end rotation by varying the applied moment. The cyclic bending could represent, in principal, localized deformations induced by the thermal deflections of primary structural components.

   A "smooth" specimen withstood 227 bending cycles before failure. A second specimen with a $K_t = 2$ (fastener hole) failed after 14 bending cycles. It should be noted that the $\frac{Mc}{I}$ stress calculated from the applied loading was approximately 100,000 psi, indicating Lockalloy's good tolerance to repeated plastic region stresses.

2. <u>Bi-Metallic Thermal Stress Test</u>

   A Lockalloy test specimen was attached through a series of bolts to an identical specimen made of titanium. The assembly, which could be representative of a portion of a high temperature structure, was heated to 600°F while restrained from bending. Max. induced thermal strains in the Lockalloy were 1000 μ in./in. which, by reference to a compressive stress/strain curve, corresponds to a compression stress of approximately 16000 psi. Thermal stress in the titanium were measured at 8440 psi. The stress distribution observed agreed closely with theoretical calculations.

3. Cyclic Reverse Bending

Reversed three point bending tests were performed on several Lockalloy strips at stresses well into the plastic range of the material. Cycles to failure at various stress levels were determined. The material demonstrated its ability to tolerate repeated straining excursions into the plastic range such as may be experienced by check and straightening operations during fabrication or after distortions incurred in-flight.

4. Column Tests - Verification of Method to Predict Allowables

Lockalloy's stress-strain relationship is relatively non-linear and exhibits a rather low proportional limit stress.

To verify the validity of stress memo 80 method to predict buckling allowable for Lockalloy as well as it does for other aircraft materials with more conventional stress-strain relationships, a series of compression and column tests were performed. Stress Memo 80 parameters were developed at R.T. and 600°F by means of autographic and strain gage methods. Strain gage data was established as the more consistent method to obtain material properties of Lockalloy. Column tests of various L/ρ ratios were performed at R.T. and 600°F. Failure loads very closely agreed with predicted buckling allowables developed by method of SM80 utilizing actual mechanical properties for the tested material.

5. Thermal Treatment

Various theremal treatments were performed to examine their effect on the mechanical properties of Lockalloy. The very limited, single point data obtained from these tests tends to indicate that the mechanical properties (in particular, the proportional limits/of as received Lockalloy. sheet might be increased by an appropriate thermal treatment. The magnitude of the increases obtained was quite small, however, and in the absence of additional data, must be considered to be within the normal test scatter of mechanical properties for this material.

6. Impact Test (Charpy)

Quantitative charpy impact-tests on various structural materials indicate that Lockalloy has an impact strength exceeding that of Beryllium and approaching the behavior of 7075-T6 aluminum.

7. Welding

A limited number of tension, fatigue and bend tests were performed on specimens prepared from electron beam buttwelded remnants of Be-38Al Lockalloy sheets machined to .100 inch thick. On the basis of ultimate tension strength, weld joint efficiencies of approximately 70% were obtained accompanied by a considerable reduction in elongation.

Based on the limited tests performed the fatigue life of welded Lockalloy appears to be equivalent to the fatigue strength of unwelded Lockalloy with a stress concentration factor of $K_t = 3$. Welded bend test samples failed to pass an R/t of 20 when bent across the weld.

X-ray of the weld joints showed some porosity which may have contributed to the loss in ductility and fatigue strength.

Development of the electron beam welding parameters could result in reduced porosity and increased strength, ductility and fatigue of welded joints.

8. Stress-Corrosion Tests

Lockalloy test specimens under stress up to 35 ksi were repeatedly immersed in a 3.5% NaCl solution for 30 days. The surface of all six (6) coupons tested showed evidence of pitting and discoloration, but none of the specimens failed or had evidence of any stress corrosion cracking.

9. Non-Destructive Testing (NDT) Methods for Inspection of Lockalloy

Samples of Lockalloy submitted to the NDT Group were evaluated to determine if NDT, as a receiving inspection tool, is capable of detecting minute discontinuities. Additionally, the specimens were evaluated to determine the response to NDT methods for possible production and field inspection applications.

In general Lockalloy responds in the same manner as most other non-ferrous materials. The only exception being the special handling requirements.

From a standpoint of surface crack detection both penetrant and eddy-current inspection may be used.

The current recommendation for receiving inspection methods of Lockalloy would be X-ray and ultrasonic. Once a criteria has been established and more data is accumulated as to types of defects inherent in this material, the possibility of inspecting by a single method is conceivable.

Production inspection can be accomplished by any of the normal NDT methods established to inspect parts after various shop operations.

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LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

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SECTION 1

CYCLIC BENDING TEST - PLASTIC RANGE

(Plastic Hinge Bending)

OBJECT

To investigate the capability of Lockalloy Be-38Al to tolerate repeated bending strains in the plastic range at an elevated temperature (600°F).

BACKGROUND

One structural concept considered for the X-24C fuselage design would have reduced overall circumferential thermal stresses by allowing segments of the main fuselage frames and Lockalloy skin to expand and rotate about pinned joints. If the fuselage skins were continuous over the joint, the skin could in effect provide the pin joint, thus greatly simplifying the design. However, the rotation at these joints due to thermal expansion of the frames during each flight would induce high bending deformation on the skin. The test was designed to investigate whether the Lockalloy skin could sustain the repeated flexing that would occur during the life of the vehicle with a factor of 4 (a life time equals one cycle per flight for 100 flights). This design concept has been referred to as "Plastic Hinge Bending."

SUMMARY

Bending tests were conducted on two Be-38Al Lockalloy sheet specimens, at 600°F, to investigate a design concept on the X-24C airplane. Four-point loading was used to simulate the amount of fuselage skin bending induced by the thermal expansion of the fuselage frames. For these tests, the specimens were deflected a specified amount in one direction, then loaded in the opposite direction to return them to their original position. The first specimen tested was of constant

cross-section (.250 x 1.500 inch), and withstood 227 bending cycles before failure. The second specimen, of the same basic dimensions, contained two .190 inch diameter holes along its longitudinal centerline to simulate a row of fastener holes. With the stress concentration produced by these holes, this specimen failed after only 14 bending cycles. These test results indicate that this particular structural arrangement would produce unacceptable bending stresses in the Lockalloy skin panels.

TEST SET-UP

Test specimens were made from Lockalloy (Be-38Al) .250 x 1.50 x 10 inches long. Two $\frac{1}{4}$ x 1.50 x $3\frac{1}{2}$ inch stainless steel plates were bolted to each side and at both ends, leaving a 3.00 inch exposed length of Lockalloy in the center, see Figure 1-1. These plates provide a bearing surface for the 5/8 diameter steel rollers used to apply the load. The plates also provide stiffness to the ends of the assembly which confine the bending deflection to the Lockalloy members over a known test length of 3.00 inches. The specimens were loaded into a fixture containing rollers for applying a four point load. Loads are applied by a "Baldwin-Wiedemann" Universal Loading Machine..

Deflection of the specimen was monitored by a "Baldwin-Wiedemann" Model PDIM deflectometer mounted at the center lower surface of the specimen. A "Federal" dial indicator was positioned to monitor the distance traveled by the upper loading point. (The difference of these distances is the calculated deflection point.)

The required elevated temperature was maintained by a "Marshall" controlled oven.

TEST PROCEDURE

The test specimens were maintained at 600°F during test.

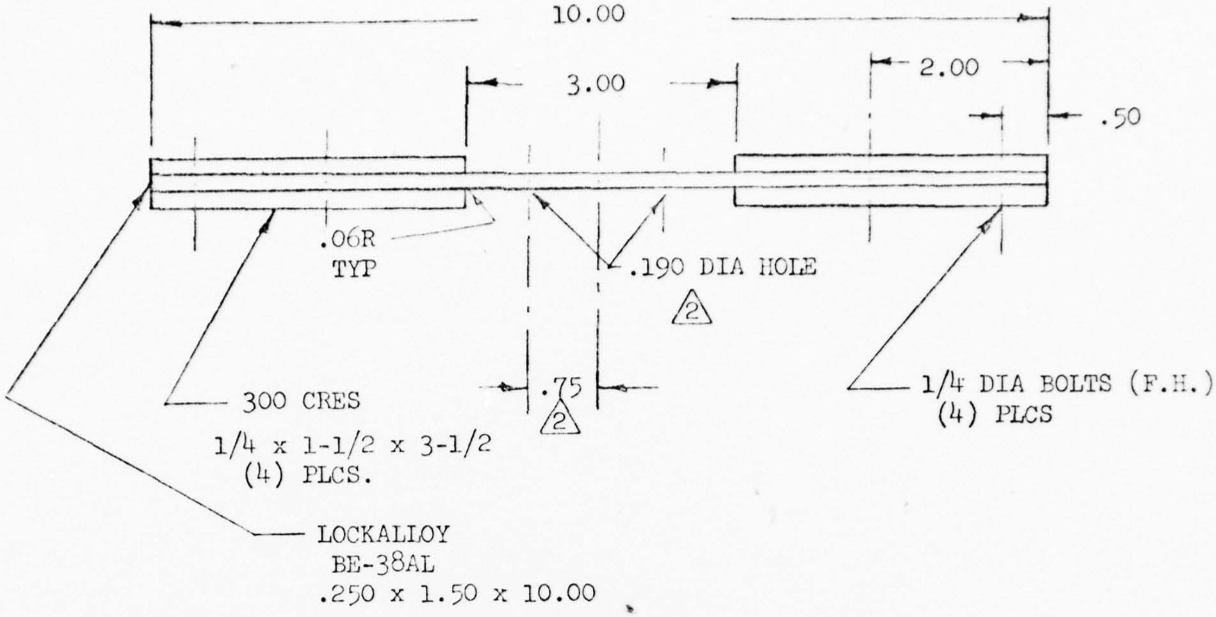
A typical deflection bend cycle is started from the normal position and deflected downward a calculated distance (Ref. Fig. 1-2), then returned to normal. To simulate the established rotation of 6° per side at the fuselage frame joint calculated bend deflection distance is used. The deflection distance is the difference between the distance of travel of the upper loading point (reading from the dial indicator) and the travel of the center point of the test specimen (deflectometer readout). This distance was initially calculated to be .065 inches and was used for the first 100 cycles on test specimen number 1 (unnotched, K_T = 1.0). A later correction changed this dimension to .087 inches (Table 1-I). The test was then continued using the .087 dimension on the same sample (No. 1).

The specimen number 2, having (2) holes to represent fastener holes (K_t = 2.0), see figure 1-1, was then tested using the same setup as used on test sample number 1, with the .087 inch defelction dimension.

TEST RESULTS

Bend testing of sample number 1 (unnotched) failed after 227 cycles (the first 100 cycles were run using a .065 inch deflection. The last 127 cycles were run with deflection dimension increased to .087 inch.)

Bend testing on sample number 2, (notched, (2).190 dia. holes) failed at 14 cycles, (see Table No. 1-I).



1. UNNOTCHED SAMPLE = NO. 1

2. NOTCHED SAMPLE = NO. 2, WITH (2) .190 DIA HOLES ON C_L

TEST SPECIMEN, PLASTIC HINGE TEST
FIG. 1-1

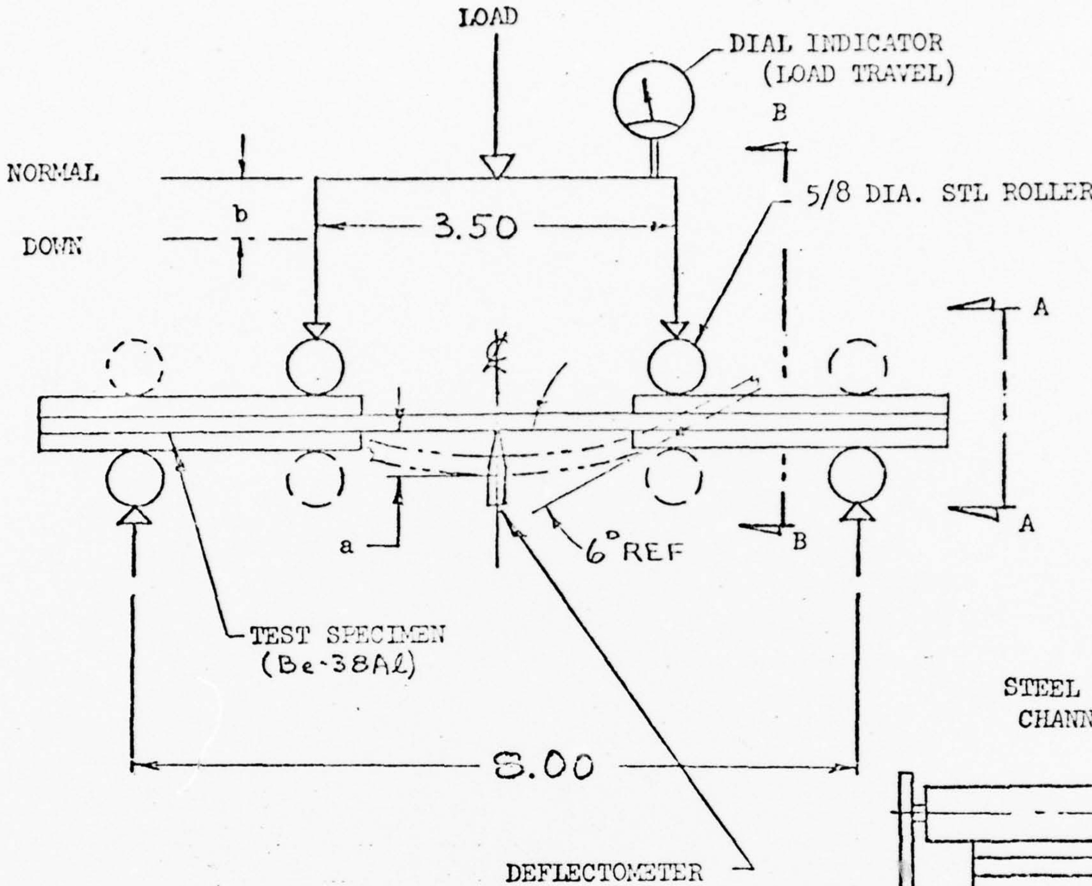
TABLE NO. 1-I

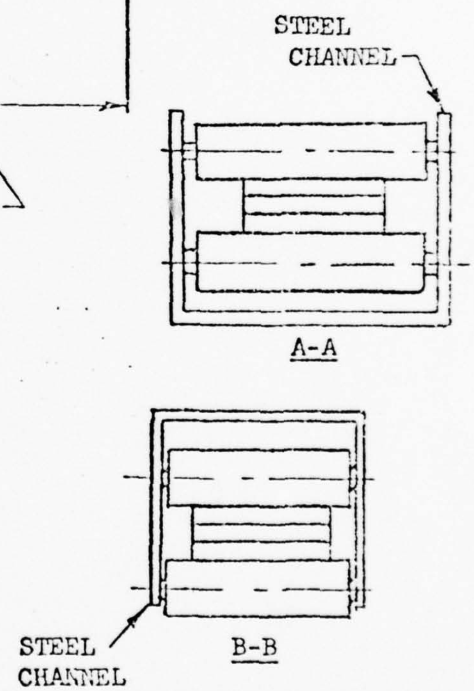
PLASTIC HINGE TEST DATA

SPECIMEN NO.	SPECIMEN K_T	DESCRIPTION	TEMP °F	DEFLECTION IN.	NO CYCLES RUN	FAILURE CYCLES
1	1.0	UNNOTCHED	600	.065	100	---
1	1.0	UNNOTCHED	600	.087	127	*127
2	2.0	NOTCHED **	600	.087	14	14

*SPECIMEN NO. 1 FAILED
ON 227 CYCLES OVERALL

**(2).190 DIA. HOLES





DEFLECTION Δ DISTANCE = a - b

○ PRIMARY LOADING ROLLERS (DOWN)

◌ ROLLERS USED FOR RETURN LOADING

NOTE: ROLLER PAIRS ARE MECHANICALLY CONNECTED. (SEE A-A & B-B)

TEST SETUP
FOUR POINT BEND TEST
FIG. 1-2

FORM 362B-2

SECTION 2

THERMAL BI-METALLIC TEST

OBJECT

To determine the thermal stresses existing within each material of a bi-metallic specimen fabricated by bolting together Lockalloy and titanium test coupons.

SUMMARY

Bi-Metallic Thermal Stress Test

A test specimen made of Titanium and Lockalloy, bolted together was heated to 600°F. Stresses are induced into the Lockalloy as a result of the different coefficient of expansion of the two materials. The magnitude of these stresses approach 10,000 psi which places the Lockalloy material in the plastic region. Since the thermal gradient anticipated on hypersonic aircraft will be much higher, greater consideration must be given to thermal stress ramifications when using Lockalloy material.

TEST SETUP

A. Specimen Details. Figure 2-1A shows details of the test specimen. Both Lockalloy and titanium specimens had identical dimensions and all bolt holes were line drilled.

B. Strain Gage Installation. Ten strain gages were installed on each specimen section - on both edges at five locations. These locations and strain gage identification are shown in Figure 2-1B. Strain gage installations were capable of withstanding 600°F and were initially cured for one hour at 600°F before any testing.

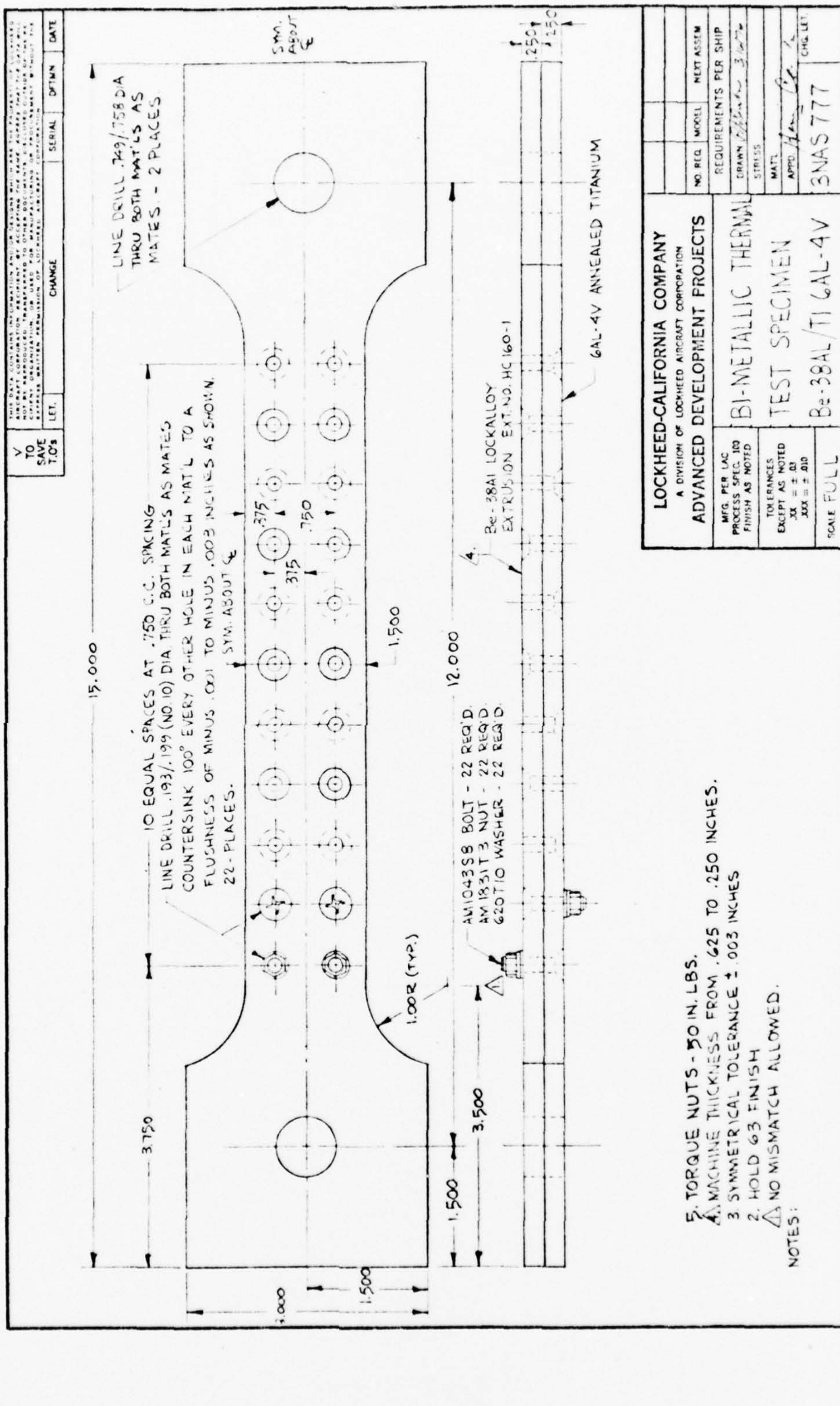
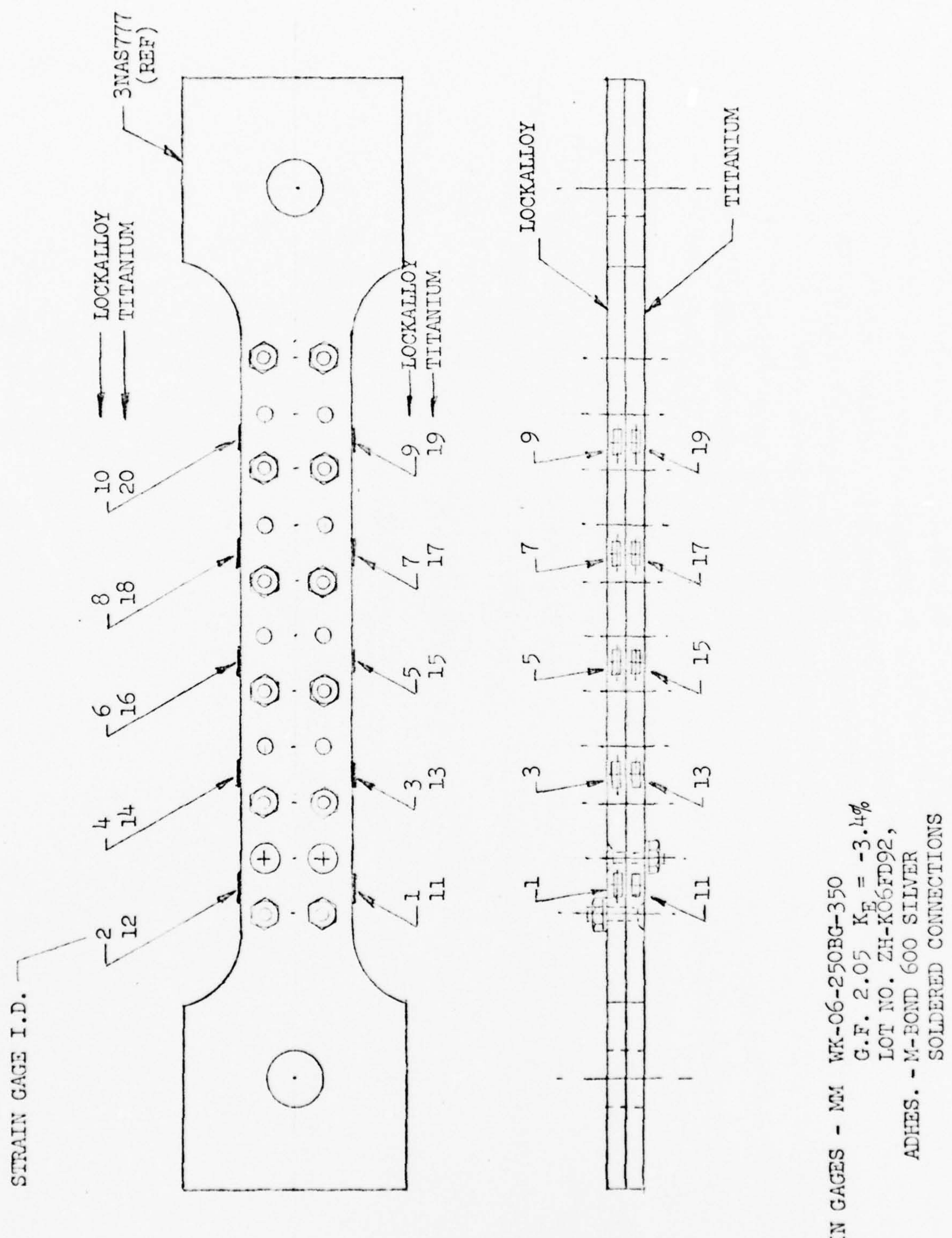

LOCKHEED-CALIFORNIA COMPANY
A DIVISION OF LOCKHEED AIRCRAFT CORPORATION
ADVANCED DEVELOPMENT PROJECTS
BI-METALLIC THERMAL
TEST SPECIMEN
Be-38AL/TI 6AL-4V
SCALE FULL
3NAS777
LINE DRILL .749/.758 DIA THRU BOTH MAT'LS AS MATES - 2 PLACES
10 EQUAL SPACES AT .750 C.C. SPACING
LINE DRILL .193/.199 (NO.10) DIA THRU BOTH MAT'LS AS MATES
COUNTERSINK 100° EVERY OTHER HOLE IN EACH MAT'L TO A
FLUSHNESS OF MINUS .001 TO MINUS .003 INCHES AS SHOWN.
SYM. ABOUT ℄
22 - PLACES.
AN10435B BOLT - 22 REQ'D.
AN 1831T3 NUT - 22 REQ'D
620T10 WASHER - 22 REQ'D
Be-38Al LOCKALLOY
EXTRUSION EXT. NO. HC 160-1
6AL-4V ANNEALED TITANIUM
SYM. ABOUT ℄
15.000
12.000
3.750
3.500
1.500
1.500
1.500
3.000
1.00R (TYP.)
.375
.750
.375
.250
.250
5. TORQUE NUTS - 50 IN. LBS.
4. MACHINE THICKNESS FROM .625 TO .250 INCHES.
3. SYMMETRICAL TOLERANCE ± .003 INCHES
2. HOLD 63 FINISH
1. NO MISMATCH ALLOWED.
NOTES:

FIGURE 2-1A

PREPARED BY	DATE	LOCKHEED-CALIFORNIA COMPANY A DIVISION OF LOCKHEED AIRCRAFT CORPORATION	PAGE
Bob Wong	6/10/76		LR 28051
CHECKED		TITLE: FIGURE 2-1B STRAIN GAGE LOCATIONS AND IDENTIFICATION THERMAL BI-METALLIC TEST.	MODEL
APPROVED			REPORT NO.



FORM 362B-2

TEST SETUP (Continued)

B. (continued)

Four strain indicators and four switch boxes were used to read the twenty strain gages. These instruments are seen in Figure 2-2.

C. Test Installation. A thermocouple was tied to the specimen for measuring temperature although the oven was automatically temperature controlled. Photographs of the load machine, oven and interior, are shown in Figures 2-2, 2-3, and 2-4.

Bowing of the bi-metallic specimen at elevated temperatures was prevented by the use of channel sections, rollers and "C: clamps as seen in Figure 2-5.

TEST PROCEDURE

Before performing the bi-metallic specimen thermal stress test, the Lockalloy and titanium coupons were individually tested to obtain "apparent strain" data and load sensitivity calibrations (Figure 2-3). These tests and the bi-metallic specimen tests were accomplished in the following steps:

1. Load calibration of the Lockalloy and titanium coupons individually at room temperature.

2. Measurement of no-load apparent strain at several temperatures up to $600^{\circ}F$.

3. Load calibration at $600^{\circ}F$.

4. Load calibration at room temperature of the bi-metallic specimen.

TEST PROCEDURE (Continued)

5. Load calibration at room temperature of the bi-metallic specimen with bending restraint installed.

6. No load thermal stress test in temperature increments up to 600°F of the bi-metallic specimen.

7. Repeat step 5 above.

TEST RESULTS

A. Individual Coupon Tests. Figures 2-6 and 2-7 compare room temperature and 600°F strain gage load calibrations for the Lockalloy and titanium coupons. At 600°F, the strain gage outputs were greater than at room temperature for the same load, showing the reduction in modulus with temperature of the materials.

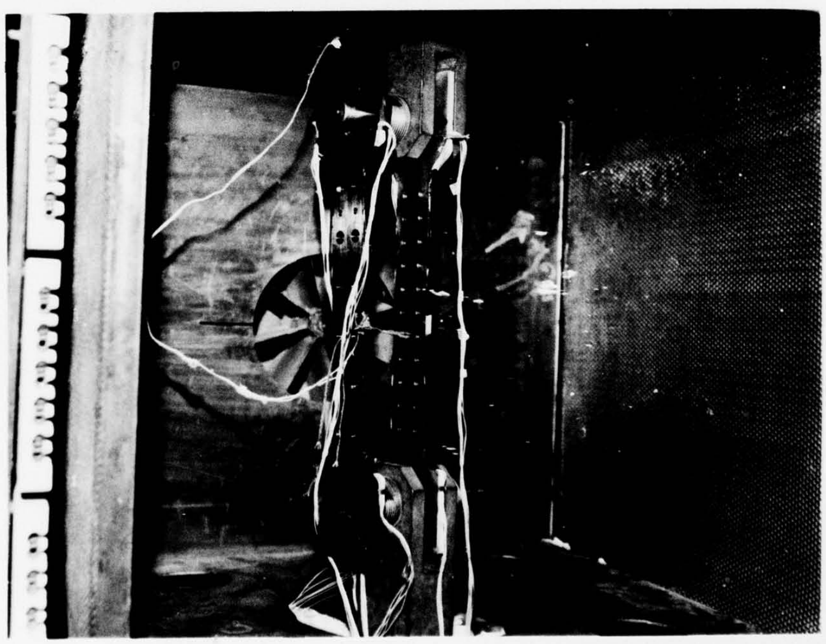
Apparent strain characteristics are shown in Figure 2-8. These are plots of the strain gage outputs due to temperature alone, and each curve shows the average of the ten strain gages on that particular coupon.

Data from the above tests were used to calculate the bi-metallic specimen thermal loads.

B. Bi-metallic Specimen Tests. After assembly of the two coupons into the single bi-metallic specimen, a strain gage load calibration was performed. Figure 2-9 shows this calibration with and without the lateral restraint installed. These tests were used to check the accuracy of the loads calculated from the strain gage outputs. At 5,000 pounds applied load, the calculated loads from the strain gage outputs in both

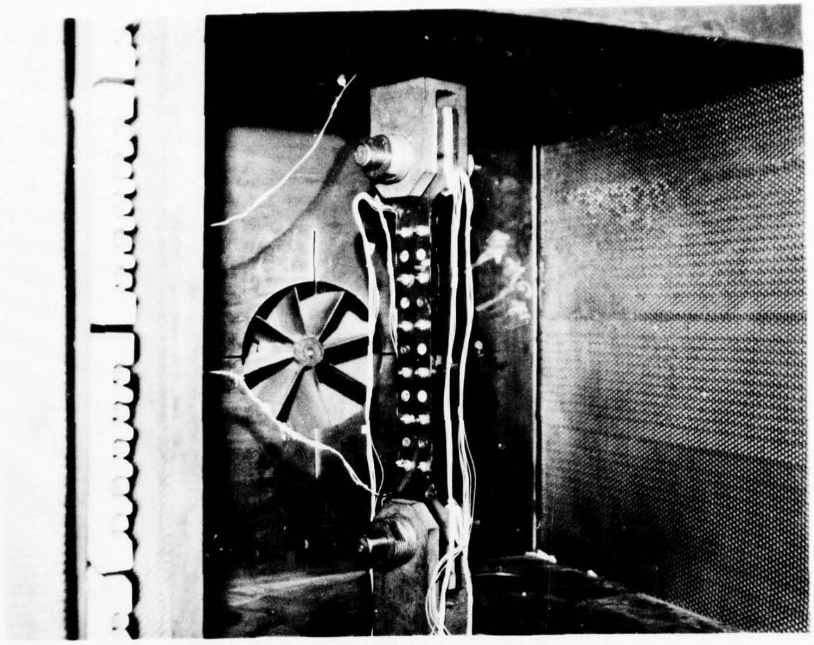
76-5197-1

Figure 2-2. Instrumentation, oven, and specimen installations.



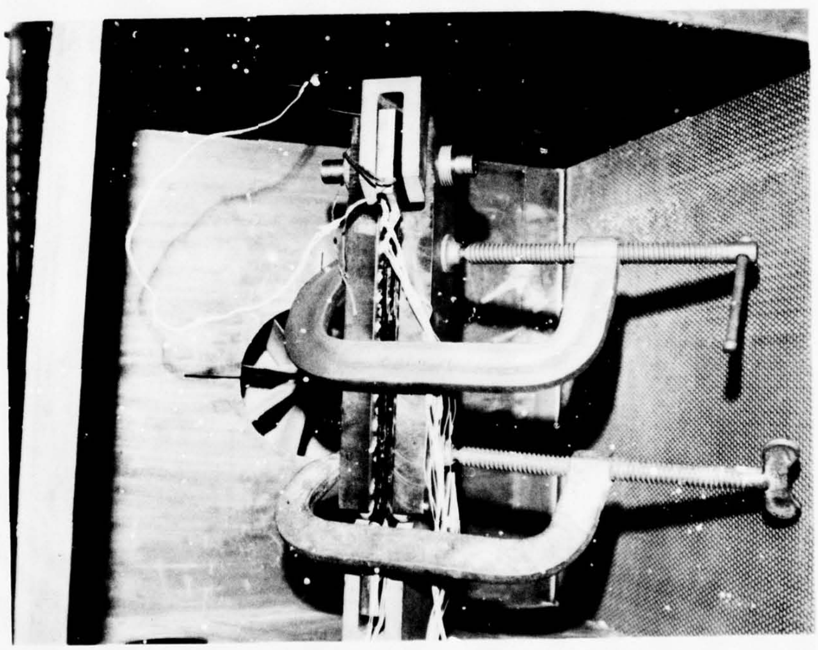
76-5197-3

Figure 2-3. Lockalloy coupon installed for load test; titanium coupon installed alongside for apparent strain measurement.



76-5197-6

Figure 2-4. Bi-metallic specimen installed for room temperature load test without side bending restraints.



76-5197-5

Figure 2-5. Bi-metallic specimen installed for thermal stress test with side bending restraints installed.

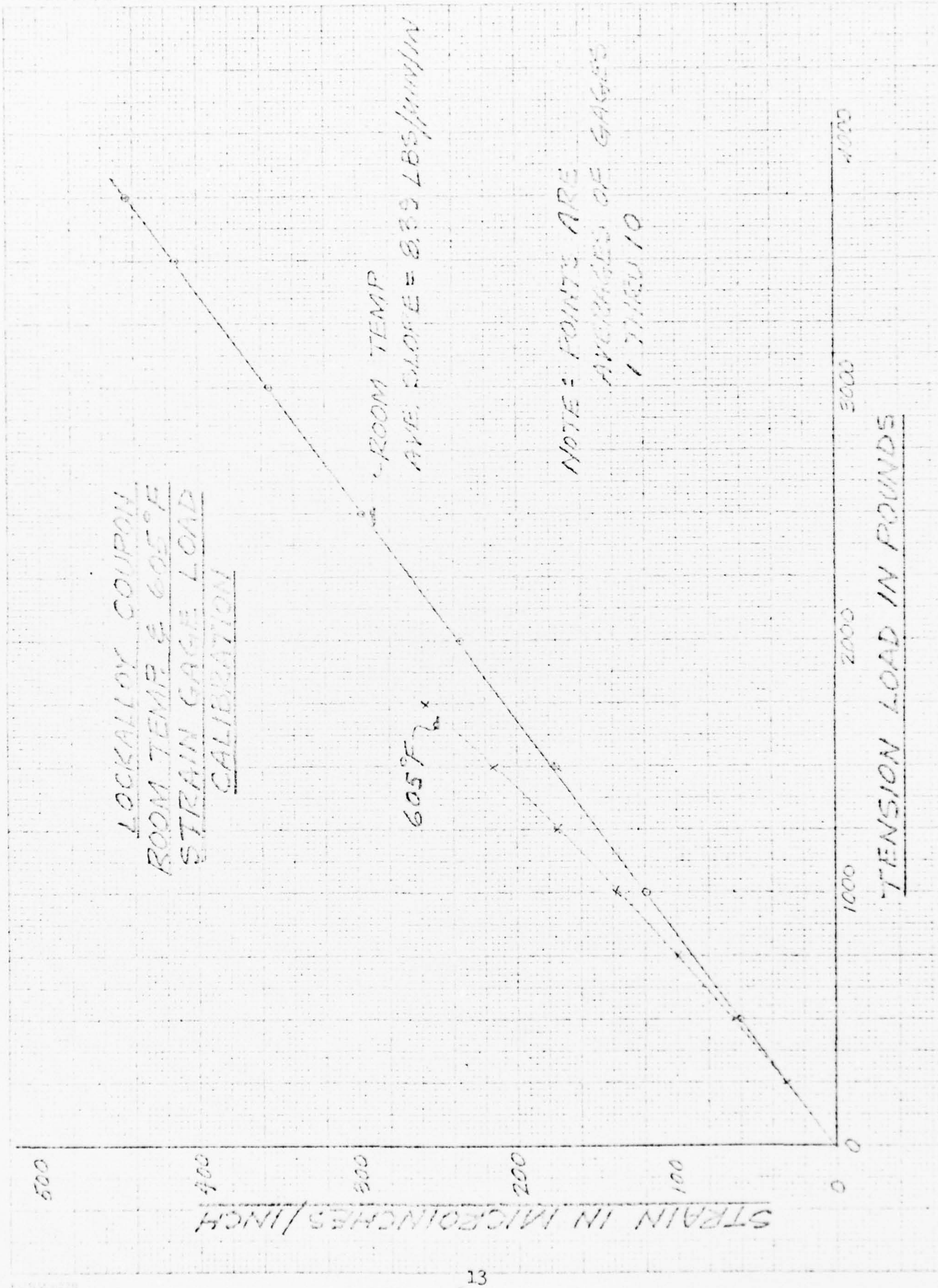

LOCKALLOY COUPON
ROOM TEMP & 605°F
STRAIN GAGE LOAD
CALIBRATION
ROOM TEMP
AVE. SLOPE = 833 LBS/µIN/IN
NOTE: POINTS ARE
AVERAGES OF GAGES
1 THRU 10
605°F
TENSION LOAD IN POUNDS
STRAIN IN MICROINCHES/INCH
0
1000
2000
3000
4000
100
200
300
400
500

FIG. 2-6

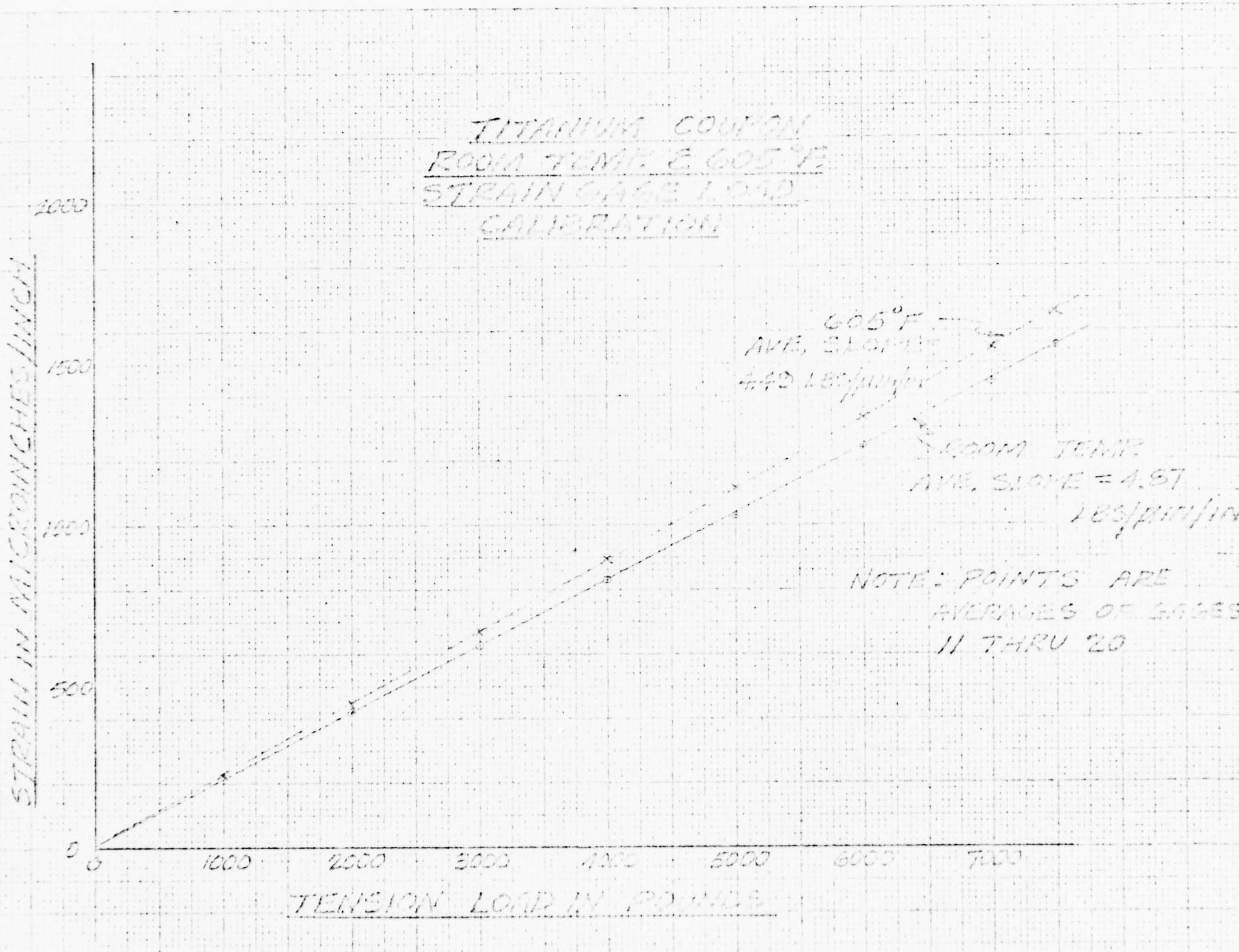
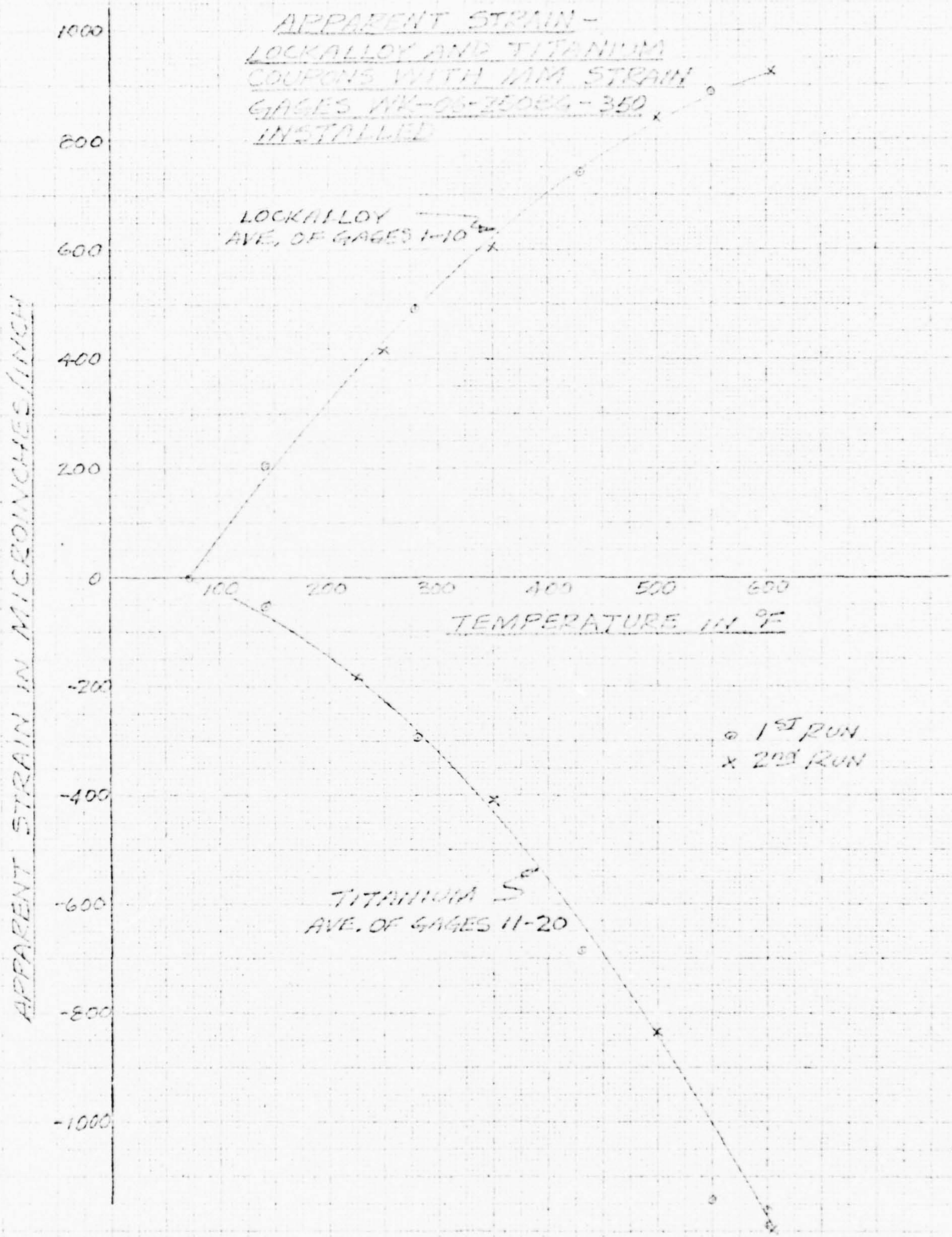
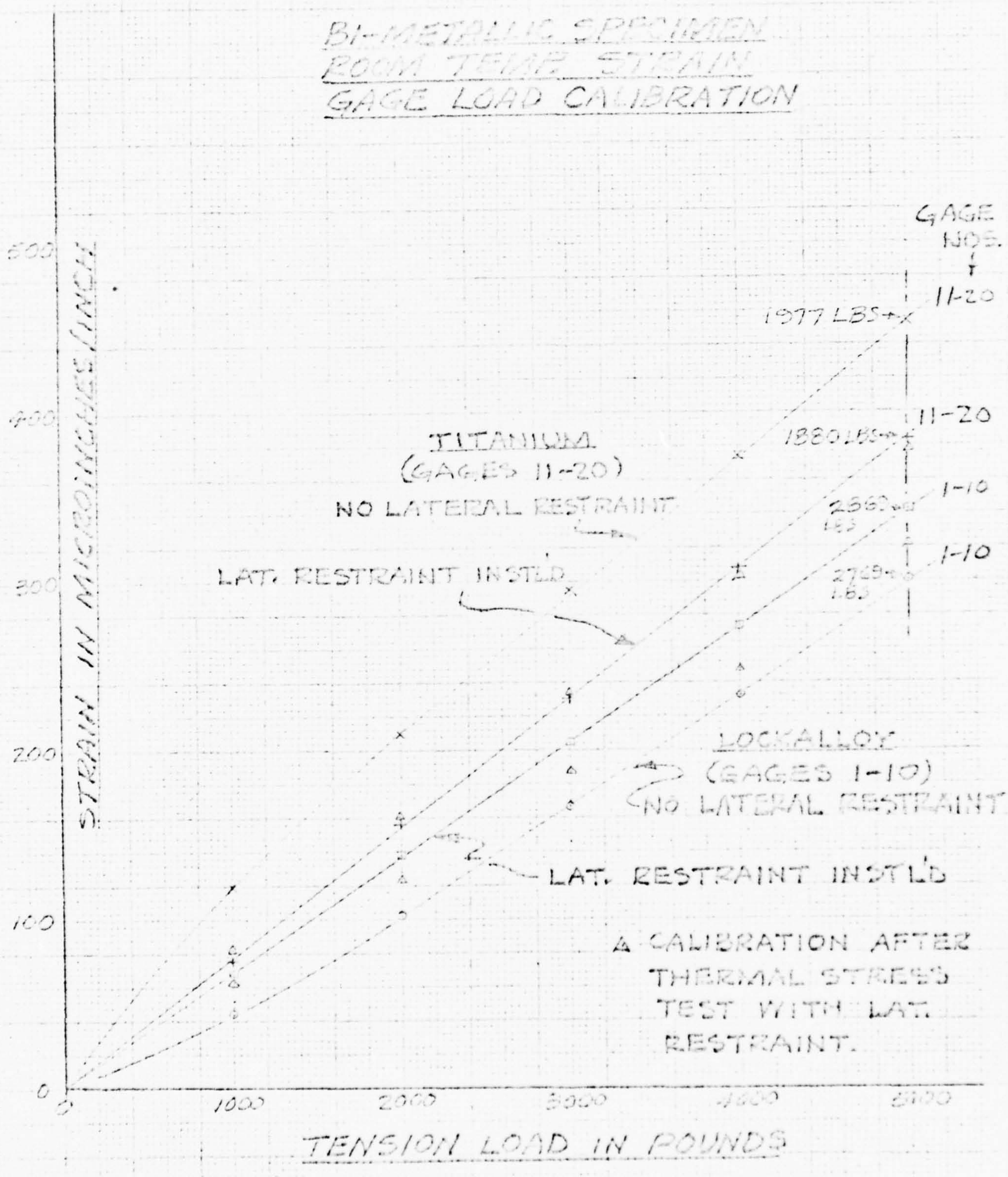

TITANIUM COUPON
ROOM TEMP. & 605°F
STRAIN GAGE LOAD
CALIBRATION
605°F
AVE. SLOPE = 4.49 LBS/μin/in
ROOM TEMP.
AVE. SLOPE = 4.87
LBS/μin/in
NOTE: POINTS ARE
AVERAGES OF GAGES
11 THRU 20
STRAIN IN MICROINCHES/INCH
0
500
1000
1500
2000
0
1000
2000
3000
4000
5000
6000
7000
TENSION LOAD IN POUNDS

FIG 2-7


APPARENT STRAIN - LOCKALLOY AND TITANIUM COUPONS WITH MM STRAIN GAGES WK-06-250BG-350 INSTALLED
LOCKALLOY
AVE. OF GAGES 1-10
TITANIUM
AVE. OF GAGES 11-20
⊙ 1ST RUN
× 2ND RUN
APPARENT STRAIN IN MICROINCHES/INCH
TEMPERATURE IN °F
1000
800
600
400
200
0
-200
-400
-600
-800
-1000
100
200
300
400
500
600


BI-METALLIC SPECIMEN
ROOM TEMP STRAIN
GAGE LOAD CALIBRATION
STRAIN IN MICROINCHES/INCH
TENSION LOAD IN POUNDS
0
100
200
300
400
500
1000
2000
3000
4000
5000
GAGE NOS.
11-20
11-20
1-10
1-10
1977 LBS
1880 LBS
2560 LBS
2769 LBS
TITANIUM
(GAGES 11-20)
NO LATERAL RESTRAINT
LAT. RESTRAINT INSTLD
LOCKALLOY
(GAGES 1-10)
NO LATERAL RESTRAINT
LAT. RESTRAINT INSTLD
△ CALIBRATION AFTER THERMAL STRESS TEST WITH LAT. RESTRAINT.

TEST RESULTS (Continued)

B. (continued)

cases indicating a 5% error in calculated loads after assembly of the coupons.

Strain gage outputs for the thermal stress test are shown plotted in Figures 2-10 and 2-11. For comparison, the apparent strain curve is also plotted. Differences between this curve and the measured strains represent thermally induced loads. These loads are tabulated in Table 2-I for several temperatures up to the peak temperature. Based on the individual gross coupon cross-sectional area of 0.375 square inches, calculated loads of approximately 6980 pounds in the Lockalloy coupon indicate the stress to be in the plastic region - over 18,600 psi. In this region, computed loads from strain gage outputs are inaccurate since load calibrations of the strain gages were performed within the proportional limit of the stress-strain curve. Maximum thermal strains in the Lockalloy were 1000 ft in/in, which, by reference to a compressive stress/strain curve at 600°F, corresponds to a compression stress of approximately 16000 psi.

Strain gage outputs on the titanium coupon show the maximum calculated thermal load of 3165 pounds at 600°F or a stress of 8440 psi which is well within the proportional limit range of 75,000 psi. The stress distribution observed agreed closely with theoretical calculations.

A room temperature load calibration of the bi-metallic specimen was performed after the thermal stress test and is plotted in Figure 2-9. The calibration results checked reasonably well with the first load calibration.

Figures 2-12 thru 2-15 show the bi-metallic specimen after the tests. A feeler gage indicates an existing bow as seen.

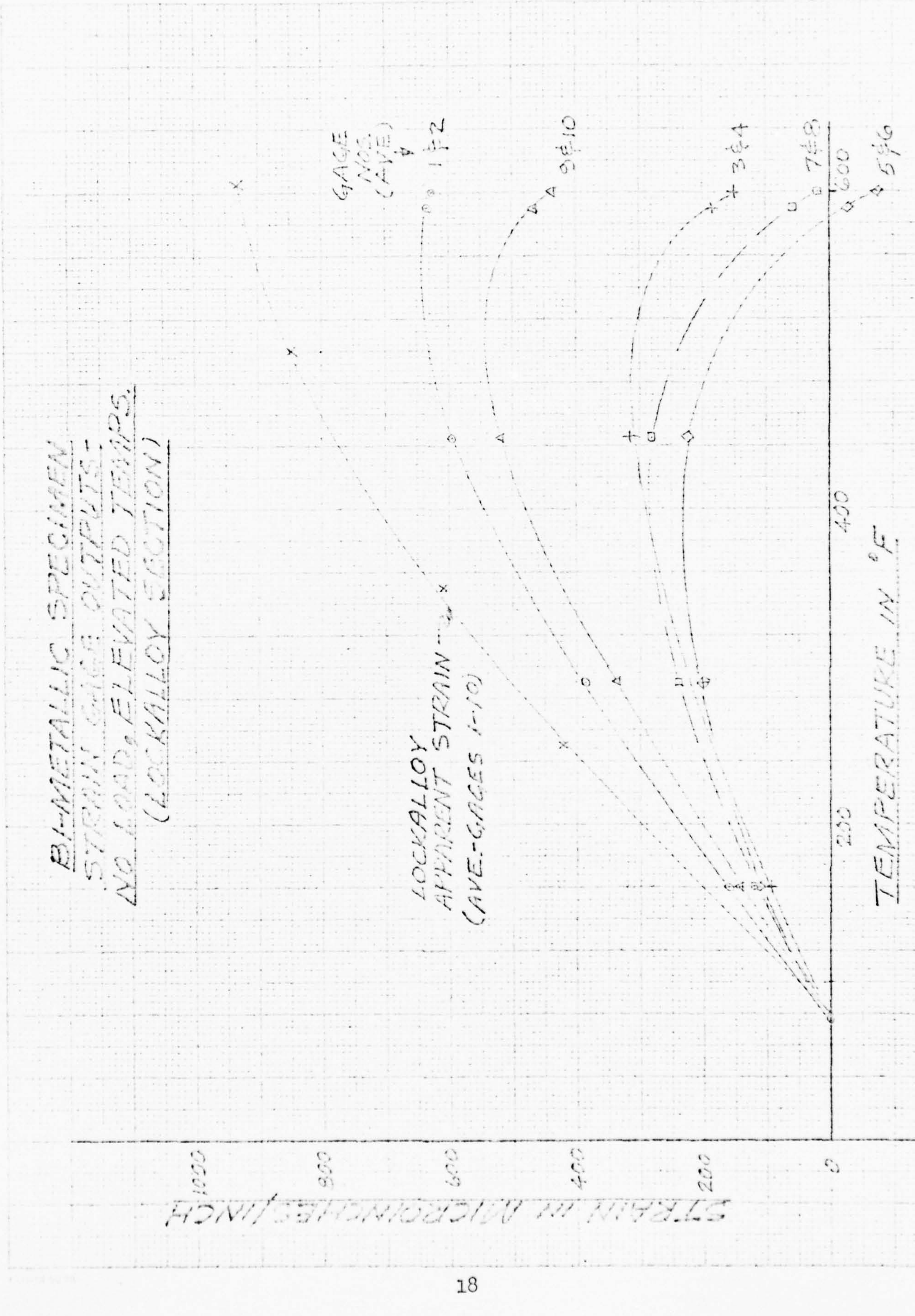

BI-METALLIC SPECIMEN
STRAIN GAGE OUTPUTS -
NO LOAD, ELEVATED TEMPS.
(LOCKALLOY SECTION)
LOCKALLOY
APPARENT STRAIN
(AVE-GAGES 1-10)
GAGE
NOS.
(AVE)
1 & 2
9 & 10
3 & 4
7 & 8
5 & 6
200
400
600
-200
0
200
400
600
800
1000
STRAIN IN MICROINCHES/INCH
TEMPERATURE IN °F

FIG. 2-10

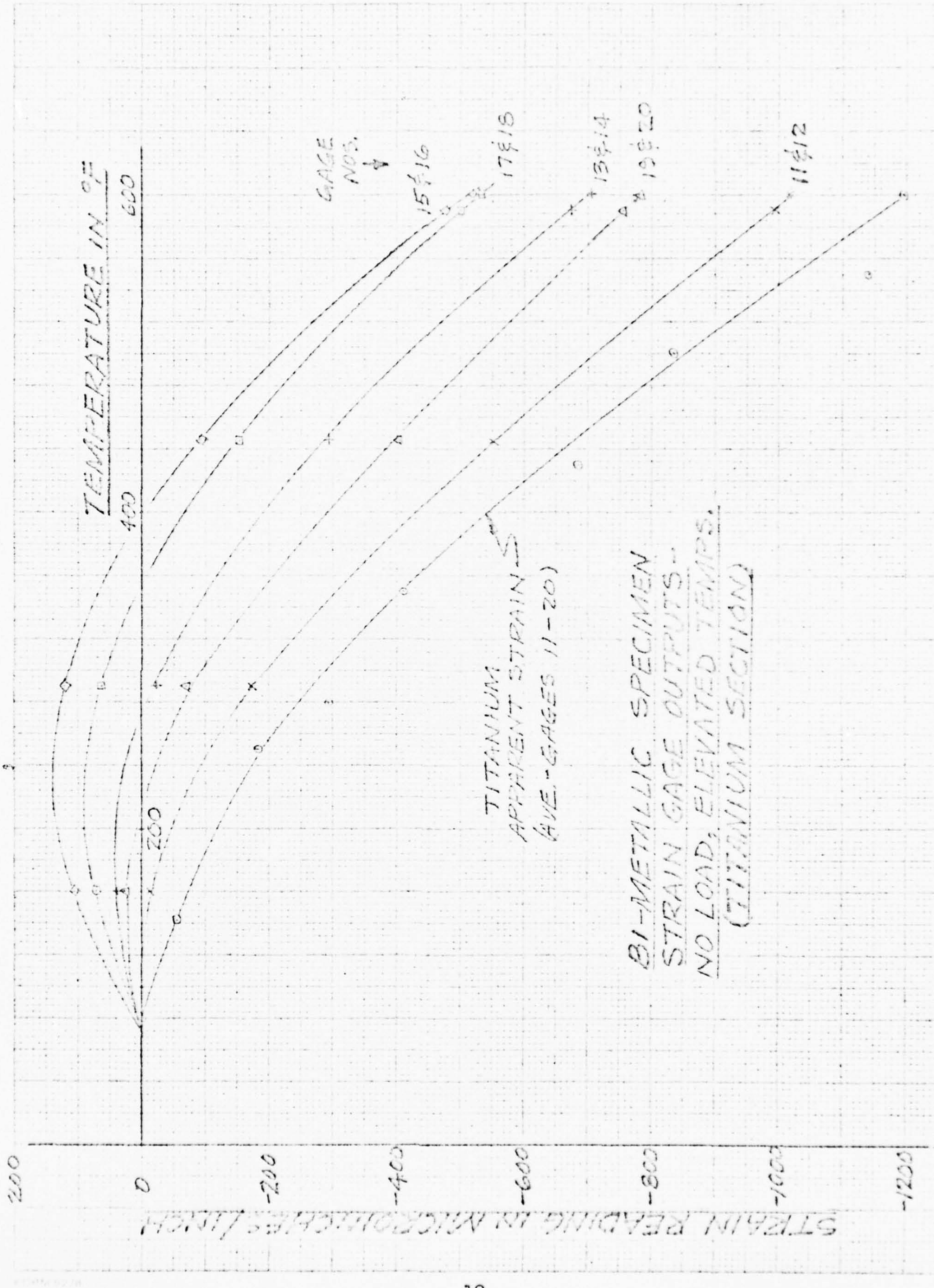

TEMPERATURE IN °F
200
400
600
STRAIN READING IN MICROINCHES/INCH
200
0
-200
-400
-600
-800
-1000
-1200
GAGE NOS.
15 & 16
17 & 18
13 & 14
19 & 20
11 & 12
TITANIUM APPARENT STRAIN AVE-GAGES 11-20)
BI-METALLIC SPECIMEN
STRAIN GAGE OUTPUTS-
NO LOAD, ELEVATED TEMPS.
(TITANIUM SECTION)

FIG. 2-11

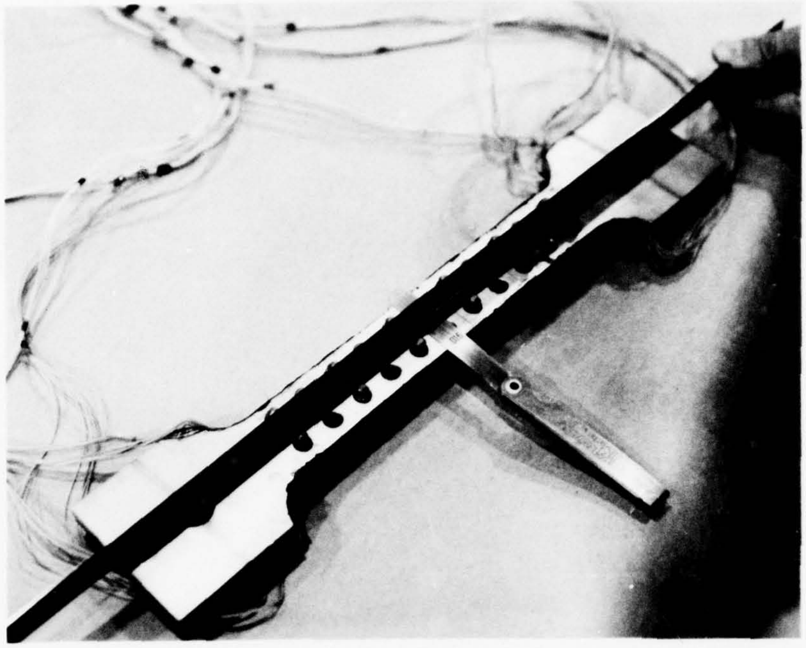
TABLE 2-I. BI-METALLIC

SPECIMEN THERMAL LOADS

	LOAD IN POUNDS			
GAGE PAIRS	160°F	290°F	445°F	600°F
1 & 2	- 686	- 1054	-1531	-2102
11 & 12	160	350	462	776
3 & 4	-1253	- 2464	-3514	-4909
13 & 14	470	1393	1830	2173
5 & 6	-1171	- 2662	-4643	-6977
15 & 16	801	2026	3000	3165
7 & 8	-1088	- 2243	-3963	-6005
17 & 18	591	1571	2508	2833
9 & 10	- 917	- 1475	-2058	-3366
19 & 20	374	870	1180	1661

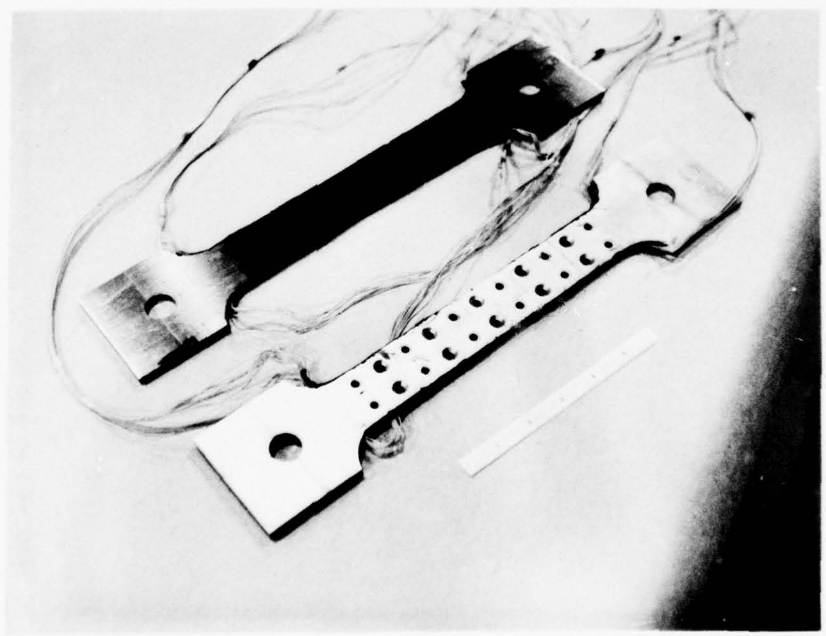
GAGES 1-10 ON LOCKALLOY COUPON

GAGES 11-20 ON TITANIUM COUPON



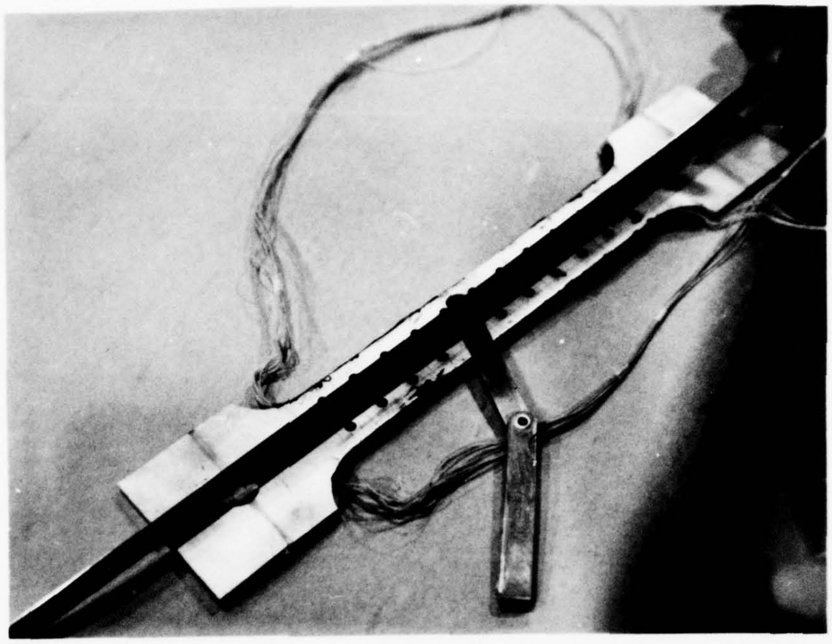
76-5197-8

Figure 2-12. Bi-metallic specimen after thermal stress test. Gap of .016 inch exists on Lockalloy side.



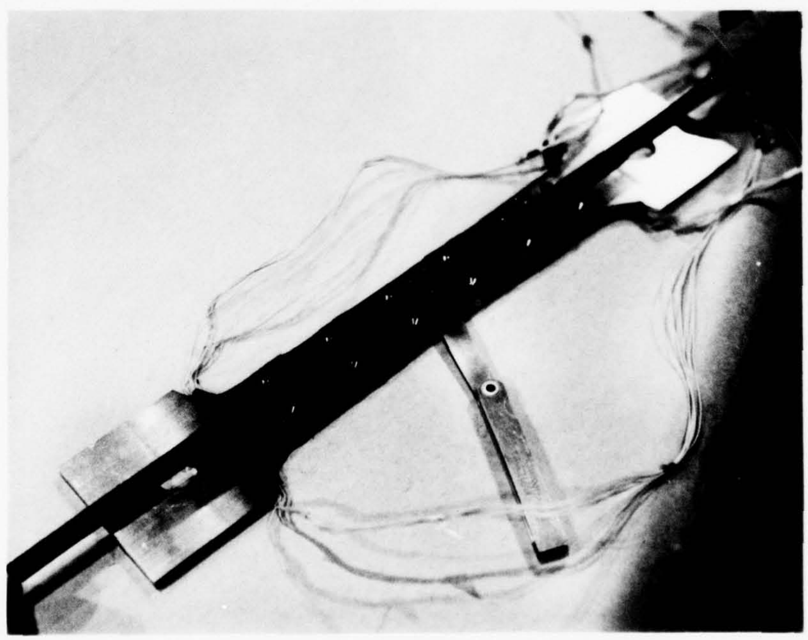
76-5197-10

Figure 2-13. Bi-metallic specimen disassembled after thermal stress test. Titanium coupon at top of photograph; Lockalloy at bottom.



76-5197-7

Figure 2-14. Lockalloy coupon after thermal stress test. Gap of .008 exists on inside surface after disassembly of bi-metallic specimen.



76-5197-9

Figure 2-15. Titanium coupon after thermal stress test. Gap of .006 exists on outside surface after disassembly of bi-metallic specimen.

SECTION 3

CYCLIC REVERSED BENDING TEST

OBJECT

To determine the durability of Lockalloy (Be-38Al) when subjected to reversed bending at stress levels above the yield strength of 35 ksi.

SUMMARY

The number of reversed bending cycles Lockalloy Be-38Al material can withstand while stressed at different levels in the plastic range is demonstrated by this test.

Specimens were tested on a simple three point bend setup by applying loads of 45 ksi, 55 ksi, 60 ksi, 67 ksi, and ultimate failure loadings of 77 ksi and 80.2 ksi. The maximum number of cycles performed was 124 at a bending stress of 55 ksi.

Considering that this bending repetition was done in the plastic region, Lockalloy exhibits excellent toughness characteristics.

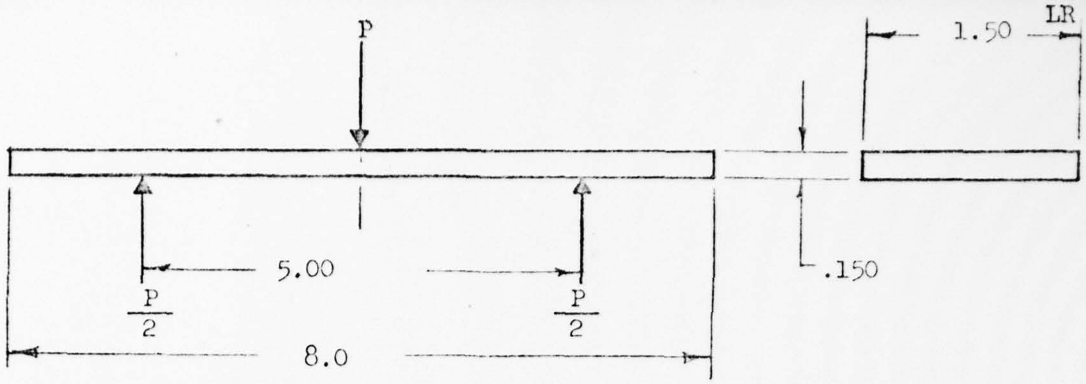
TEST SETUP

Three (3) bend test specimens each having the dimensions of .150 x 1.5 x 8.0 inches in the longitudinal direction were three-point loaded as shown in Fig. 3-1. Two additional 5 inch specimens were fabricated from one of the 8 inch coupons and loaded as shown in Figure 3-2. Loading was applied at midspan by means of a Weideman-Baldwin testing machine. Also at midspan, deflection was measured using a Weideman-Baldwin Deflectometer. Views of the test set-up are shown in Figures 3-3 and 3-4.

The test consisted of cycling a strip of Lockalloy through a reverse bend loading. The hysteresis in both directions was obtained by monitoring the load-deflection curves for the first and every tenth cycle. The specimen was loaded twice on the same side before reversing it and then repeating the loading on the other side.

RESULTS

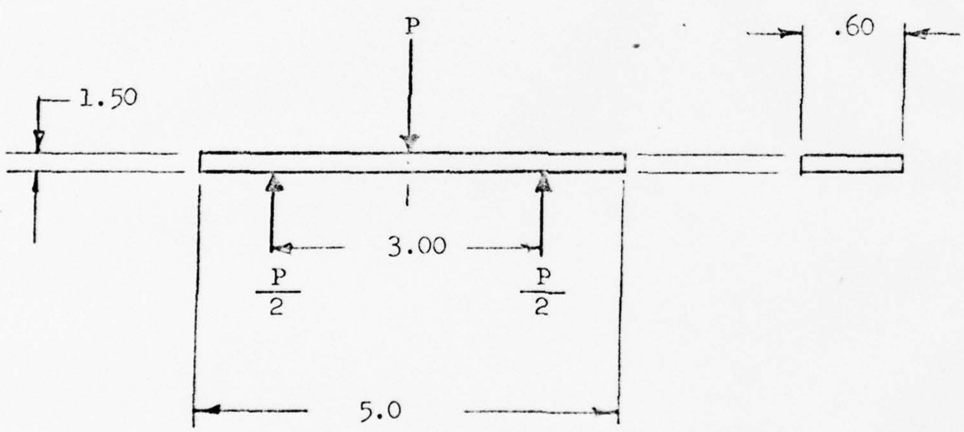
Hysteresis curves were plotted for each maximum loading made in the plastic region of Lockalloy, showing the compression versus deflection of each specimen over the specified number of cycles. Typical samples of these curves are shown in Figures 3-5 and 3-6. The repeated close deformation comparison over the respective test cycles exhibit the excellent toughness qualities in the plastic region. Specimen test data is graphically shown in Figure 3-7 and list in Table 3-I.



TEST SPECIMENS NO. 4UB-4L, -5L & 4BM-4L

THREE-POINT BEND LOADING

FIGURE 3-1

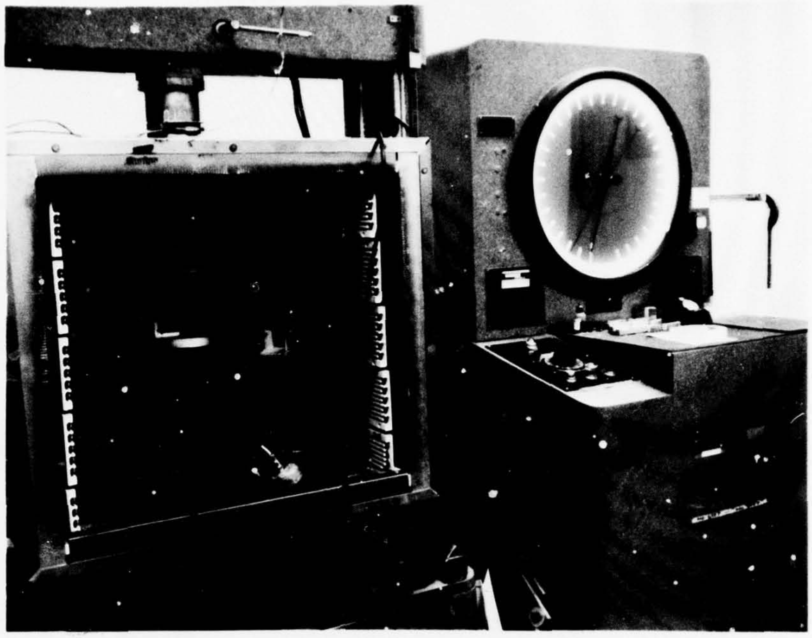


TEST SPECIMENS NO. 4UB-5L-1, -2 (MADE

FROM REMNANT HALF OF 4UB-5L) AND

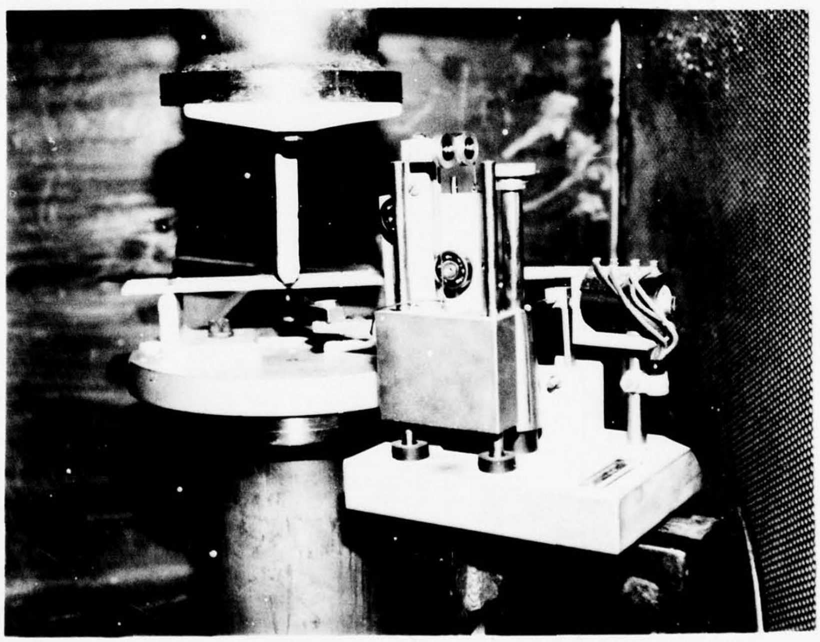
THREE-POINT BEND LOADING

FIGURE 3-2



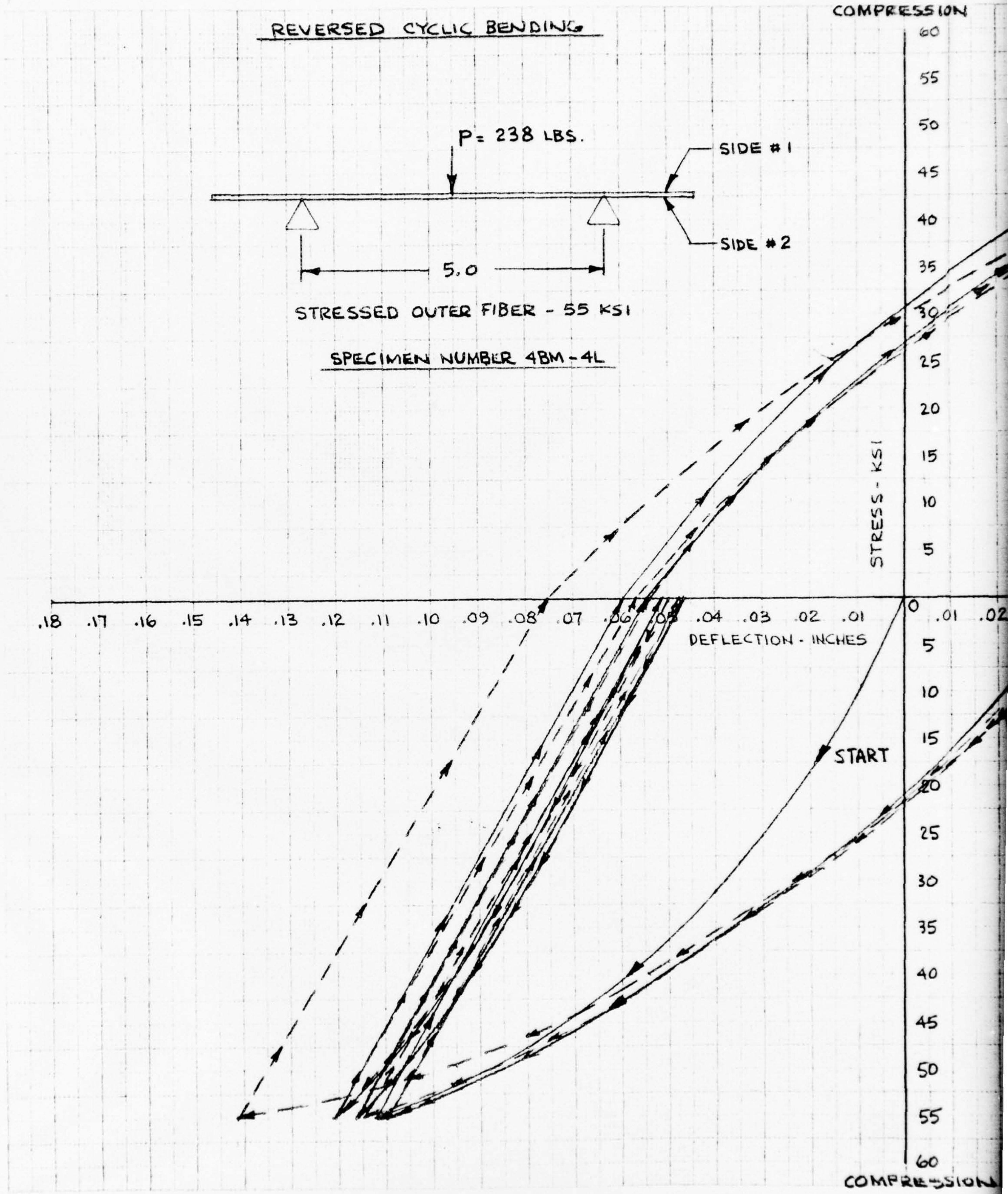
75-5405-1

Figure 3-3 - Test specimen and Weideman-Baldwin Test Apparatus (oven is not utilized for this test)



75-5405-2

Figure 3-4 - Closeup of Test Specimen and Deflectometer Setup


REVERSED CYCLIC BENDING
P = 238 LBS.
SIDE #1
SIDE #2
5.0
STRESSED OUTER FIBER - 55 KSI
SPECIMEN NUMBER 4BM-4L
COMPRESSION
STRESS - KSI
60
55
50
45
40
35
30
25
20
15
10
5
0
.18 .17 .16 .15 .14 .13 .12 .11 .10 .09 .08 .07 .06 .05 .04 .03 .02 .01
.01 .02
DEFLECTION - INCHES
START
COMPRESSION

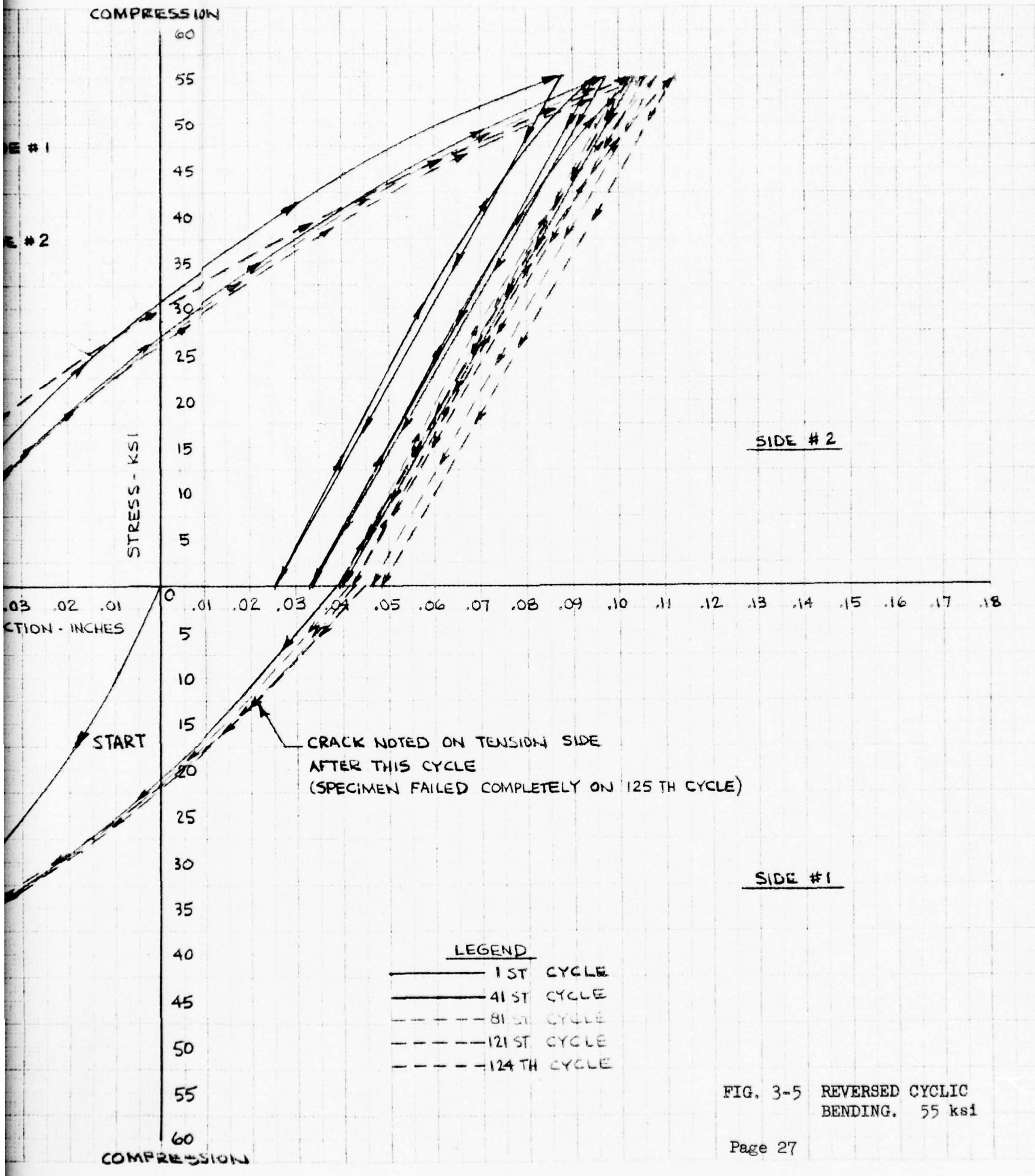
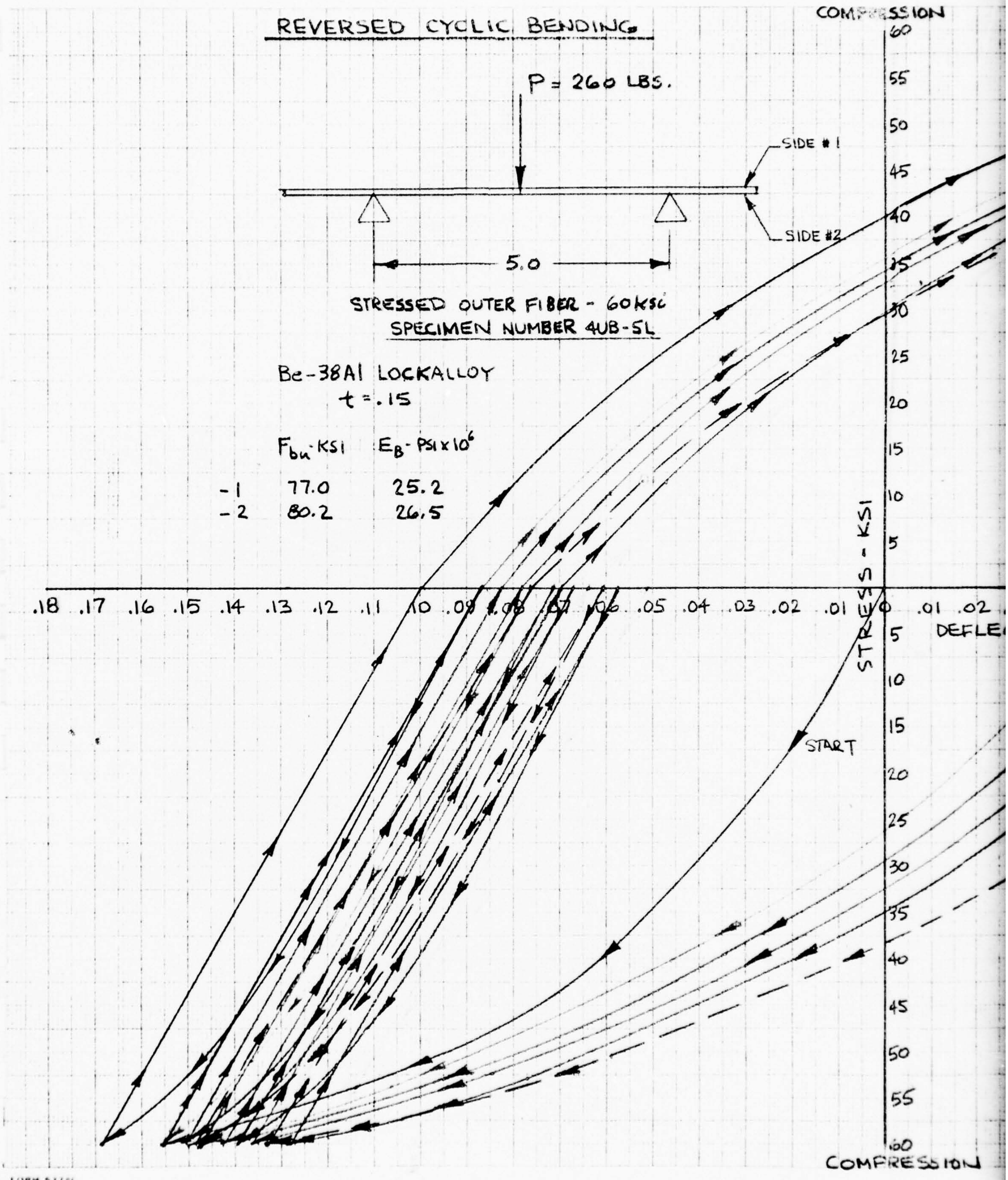


FIG. 3-5 REVERSED CYCLIC BENDING. 55 ksi


REVERSED CYCLIC BENDING
P = 260 LBS.
SIDE #1
SIDE #2
5.0
STRESSED OUTER FIBER - 60 KSI
SPECIMEN NUMBER 4UB-5L
Be-38Al LOCKALLOY
t = .15
F_{bu}-KSI E_B-PSI x 10^6
-1 77.0 25.2
-2 80.2 26.5
COMPRESSION
STRESS - KSI
DEFLE
START
.18 .17 .16 .15 .14 .13 .12 .11 .10 .09 .08 .07 .06 .05 .04 .03 .02 .01 0 .01 .02
60 55 50 45 40 35 30 25 20 15 10 5 5 10 15 20 25 30 35 40 45 50 55 60
COMPRESSION

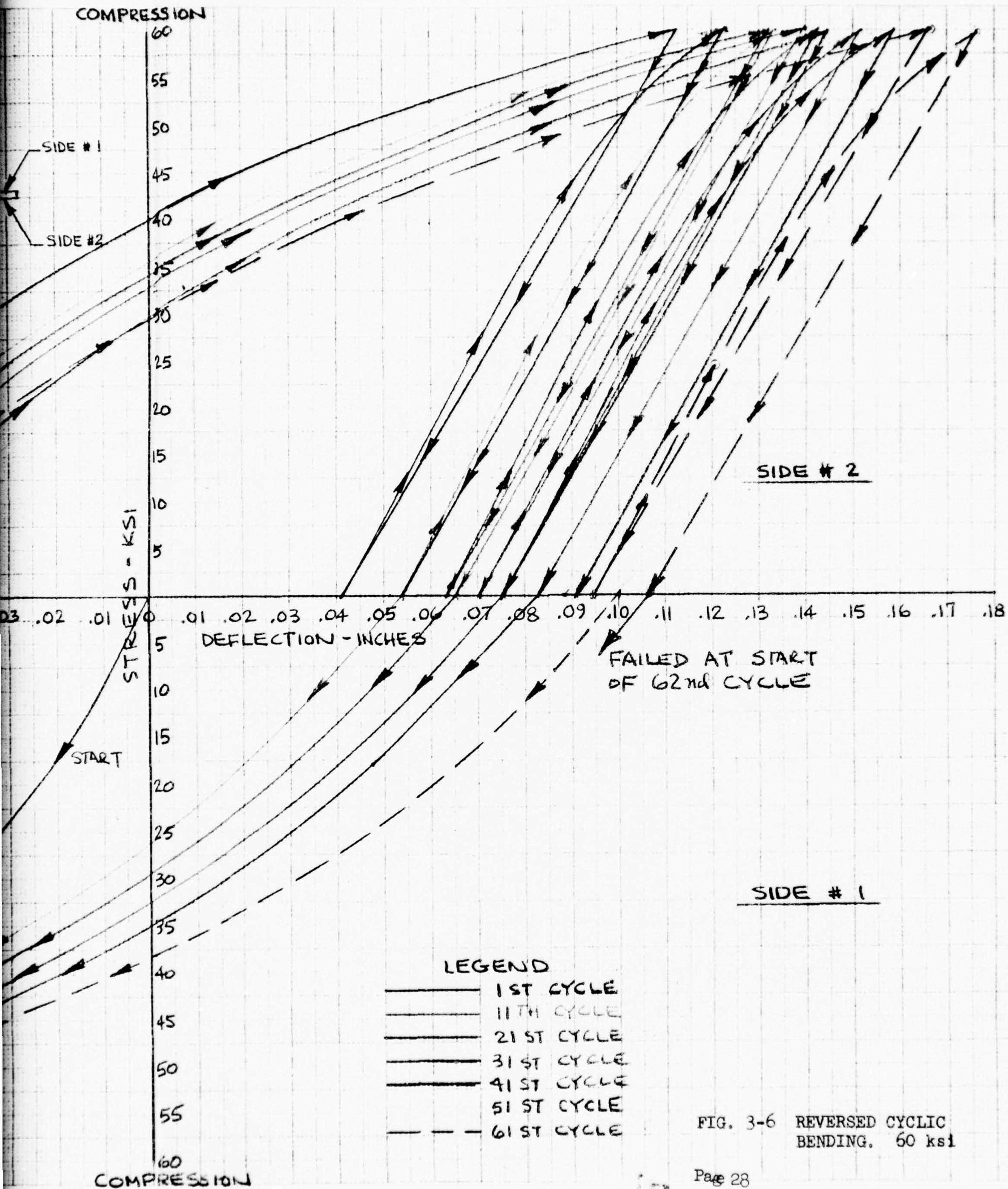


FIG. 3-6 REVERSED CYCLIC BENDING. 60 ksi

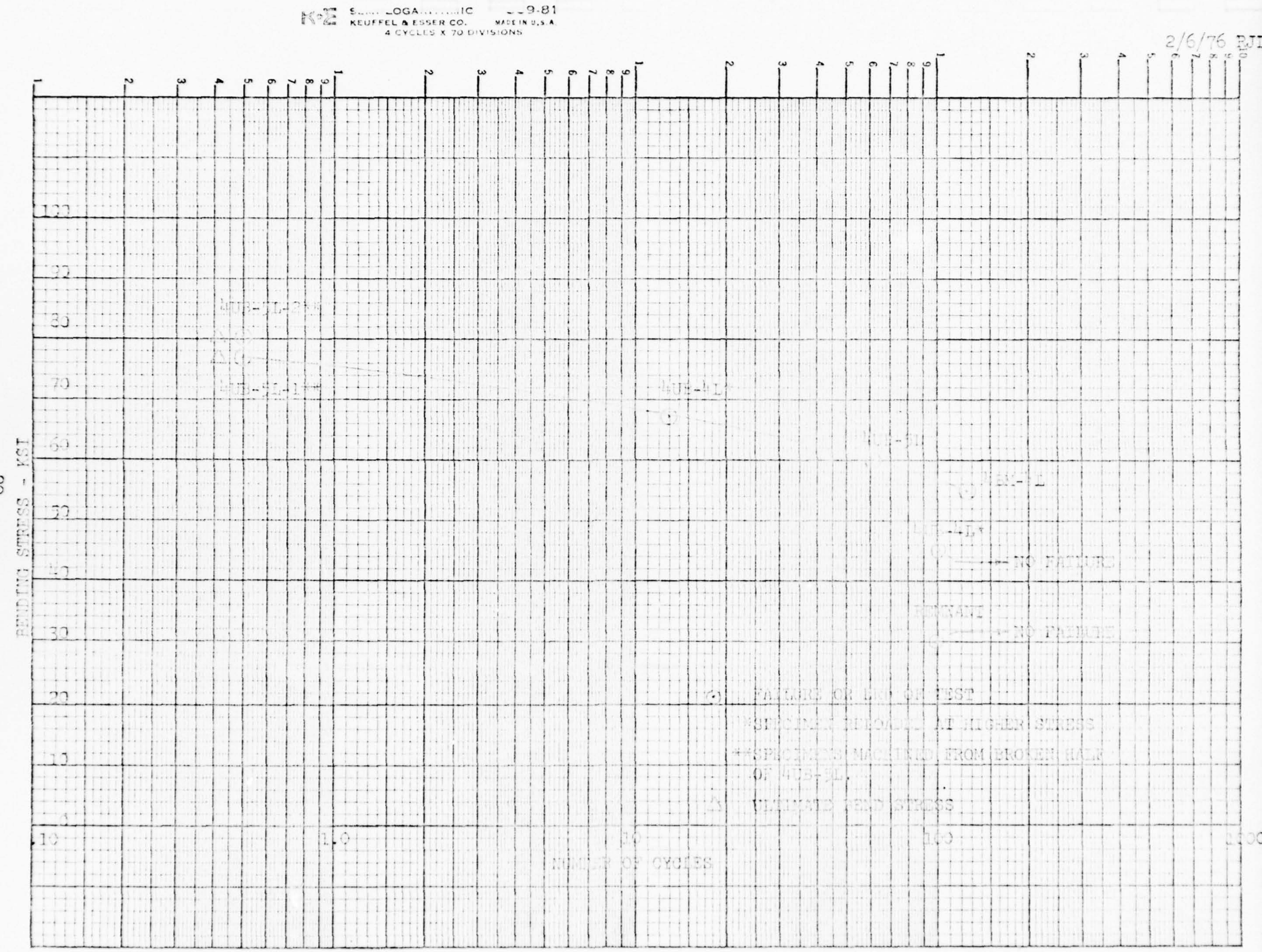


FIG. 3-7 - REVERSED CYCLIC BENDING TEST RESULTS

CYCLIC REVERSED BEND TEST

AT ROOM TEMPERATURE

TABLE 3-I TEST RESULTS

SPECIMEN NO.	K_{SI}	NO. OF COMPLETE CYCLES RUN	FAILURE (CYCLE)
4UB-4L	45	101	*
4BM-4L	55	123	124
4UB-5L	60	61	62
4UB-4L**	66.9	12	13
4UB-5L-1	77	0	1/2
4UB-5L-2	80.2	0	1/2

*Unloaded - No Failure

**Sample Retested at Higher Load

SECTION 4

DETERMINATION OF MODULUS OF ELASTICITY AND COLUMN STRENGTH PREDICTION METHODS.

OBJECTIVES

(a) To determine method of obtaining consistent and reliable material property data.

(b) To verify that methods used to predict column allowables are consistent with experimentally obtained column failure loads.

(c) To determine Modulus of Elasticity from coupon data at room temperature and 600°F.

SUMMARY

Material properties were determined by tension and compression tests on coupons fabricated from two sheets of Be-38Al Lockalloy. Column failure was determined by testing long and short column specimens from the same two sheets.

Compression and tensile mechanical properties were monitored by strain-gages and extensometers. The data from strain-gages proved to have less scatter than the extensometer data. The data from strain-gages was established as the more consistent method to obtain material properties of Lockalloy.

Analysis of data from testing long and short columns at room temperature and 600°F indicate that the methods currently used to predict column allowables for other structural materials apply equally to Lockalloy.

SUMMARY (Continued)

As the result of testing strain-gaged tensile and compressive test specimens, the following modulii are recommended for Be-38Al Lockalloy:

Modulus	Room Temp.	$600^{o}F$
E, 10^6 P_{si}	28.0	20.0
E_c, 10^6 P_{si}	27.0	22.0

DESCRIPTION OF TEST SPECIMENS

The test specimens used for the series of column tests were cut out of two different sheets of Lockalloy Be-38Al. Each sheet was selected from different manufacturing heats. The sheets are identified as HC 348-1 and HC 409-3. These identification numbers are used throughout the test series assuring that every test condition is performed on a specimen from each heat.

Material certification information furnished by the Lockalloy Manufacturer (KBI) and subsequent verification data by ADP is shown in Table 4-I.

The coupon layout for each sheet is found on ADP drawings 3NAS 796 and 3NAS 784. Configurations for the three types of coupons used are shown in the figures listed below:

Specimen Type	Size (Measured Gage Area) Inch t x w x L	Figure No.
Column* Test Specimen	.156 x 1.50 x 11.15	4-1
	.156 x 1.50 x 10.15	4-1
	.156 x 1.50 x 9.13	4-1
	.156 x 1.50 x 8.13	4-1
	.156 x 1.50 x 5.39	4-1
	.156 x 1.50 x 2.62	4-1
	.156 x 1.50 x 10.14	4-1
	.156 x 1.50 x 9.13	4-1
	.156 x 1.50 x 8.14	4-1
	.156 x 1.50 x 5.42	4-1
	.156 x 1.50 x 2.65	4-1
Compression Test Specimen	.156 x .625 x 3.10	4-2
Tension Test Specimen	.156 x .500 x 2.00	4-3

*A pair of steel blocks (1.0 x 1.5 x 1.5 inches) is bolted to each end of the column coupon (Figure 4-1). The resulting end restraint provides a fixity factor (C) equal to four.

TABLE 4-I LOCKALLOY SHEET MATERIAL

CERTIFICATION AND VERIFICATION

SHEET NUMBER HC 348-1

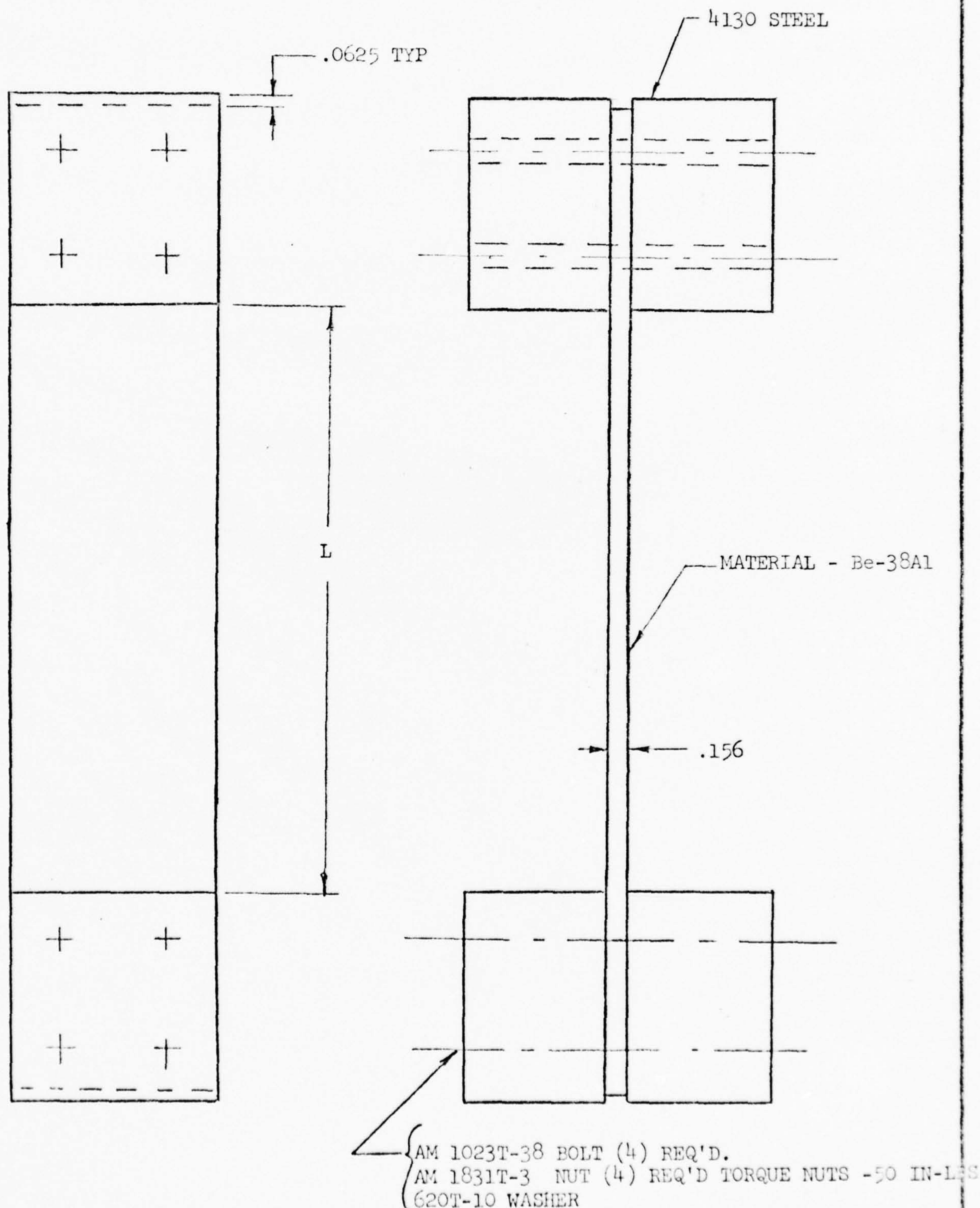
	*KBI						ADP			
PROPERTY \ SPECIMEN NO.	1L	2L	AVE	1T	2T	AVE	1T	2T	3T	AVE
F_{TU} - ksi	52.5	53.3	52.9	50.6	52.0	51.3	52.3	52.5	53.6	52.8
F_{TY} - ksi	39.0	38.8	38.9	38.2	39.5	38.8	38.7	40.0	39.5	39.4
e - %	12.5	12.0	12.2	7.0	14.0	10.5	8.5	9.5	11.0	9.3

SHEET NUMBER HC 409-3

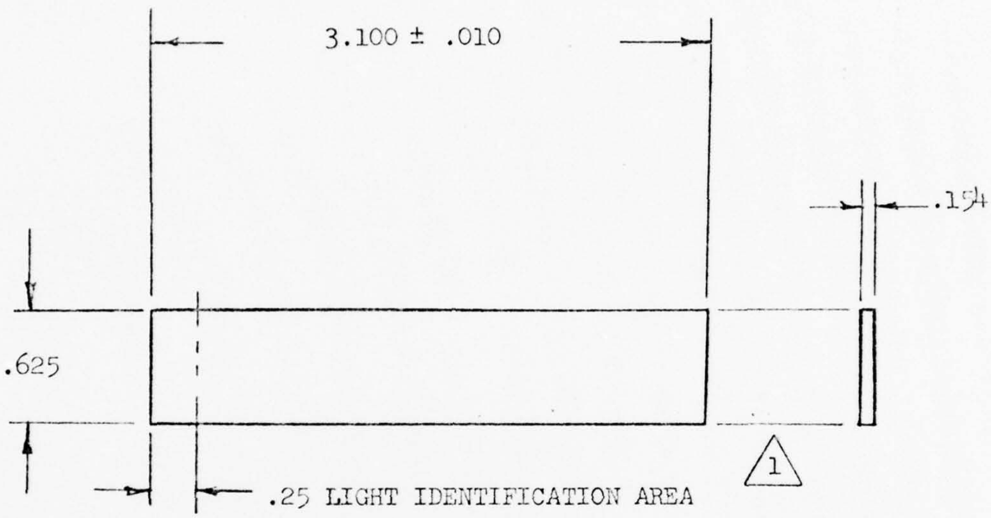
F_{TU} -	50.3	50.5	50.4	50.5	50.4	50.5	51.4	51.2	51.1	51.2
F_{TY} - ksi	37.6	37.0	37.3	37.4	36.9	37.2	36.9	36.6	35.3	36.3
e - %	11.5	11.5	11.5	11.4	10.0	10.7	8.5	8.5	10.0	9.0

*KAWECKI BERYLCO INDUSTRIES, INC.

PREPARED BY	DATE	LOCKHEED-CALIFORNIA COMPANY A DIVISION OF LOCKHEED AIRCRAFT CORPORATION	PAGE
CHECKED		TITLE FIG. 4-1 COLUMN TEST SPECIMEN	MODEL
APPROVED			REPORT NO. LR 20051



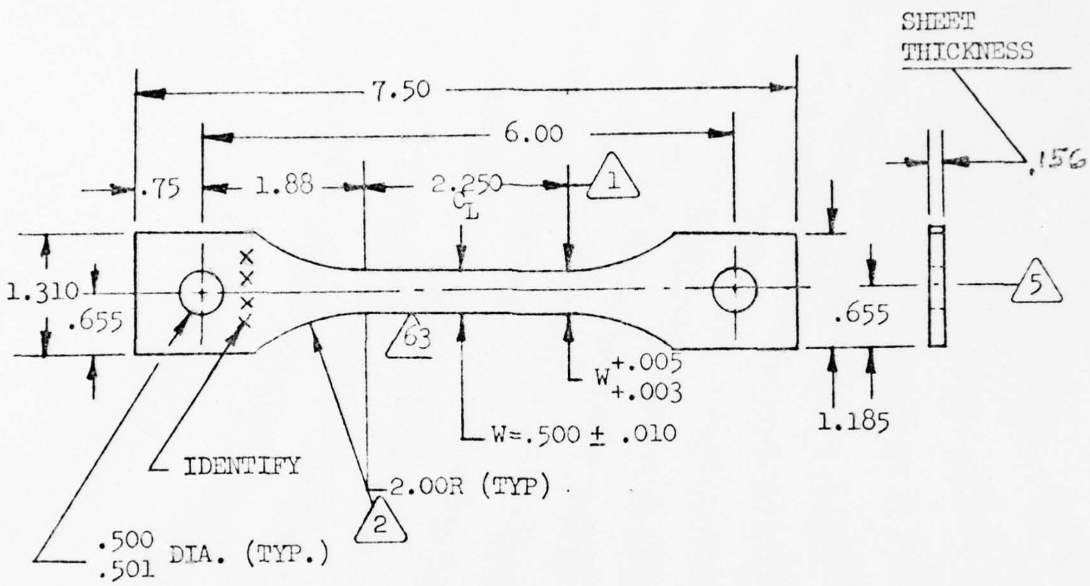
FORM 362B-2



NOTE: 1 ALL EDGES TO BE GROUND TO 63 FINISH AND MUST BE FLAT, SQUARE, AND PARALLEL

2 LEAVE ALL EDGES SHARP

FIG. 4-2. COMPRESSION COUPON



TENSION COUPON - 2 INCH GAGE LENGTH - SHEET

NOTE: 1 DIMENSION AT ENDS OF THIS GAGE LENGTH MUST BE LARGER BY +.003 TO +.005 INCHES THAN THE W = .500 ±.010 INCHES AT CENTERLINE. RADIUS TAPER FROM ENDS TO CENTERLINE REQUIRED.

2 NO MISMATCH ALLOWED.

3. USE FOR ELEVATED TEMPERATURE TESTS

4. LEAVE ALL EDGES SHARP

5 SYMMETRICAL TOLERANCE ±.001

FIG. 4-3 - TENSION COUPON - 2 INCH GAGE LENGTH

Column Test

Column test specimens (Fig. 4-1) were tested in a 30,000 lb Baldwin Mark B Universal Testing Machine (Fig. 4-4). Each specimen was compression loaded at a rate of .005 inch/inch/minute until failure was noted by a drop in load on the test machine dial. A typical failed specimen is shown in Figure 4-5. Specimens from both material sheets were column tested at room temperature and 600°F. A sampling of the specimens before and after the column test are shown in Figures 4-6 thru 4-8.

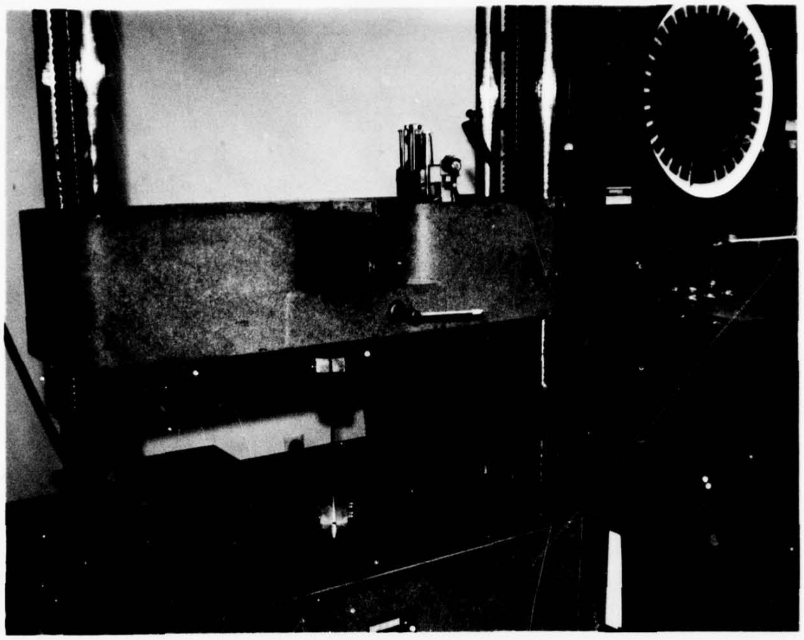
A comparison of these column test results to predicted failure stresses obtained on the bases of previously established design material parameters and the methods of Stress Memo 80, is shown in Table 4-II.

Compression Tests

Compression tests were conducted according to standard ASTM E9-70 practices. Compression test coupons of the configuration shown in Figure 4-2 were loaded into a Lockheed designed compressive fixture between the platens of a 30,000 lb Bladwin Mark B Universal Testing Machine. The general set-up is shown in Figure 4-10. This set-up was used for both room and elevated temperature testing. The specimens were loaded at a constant rate of .005 inch/per/inch/per/minute.

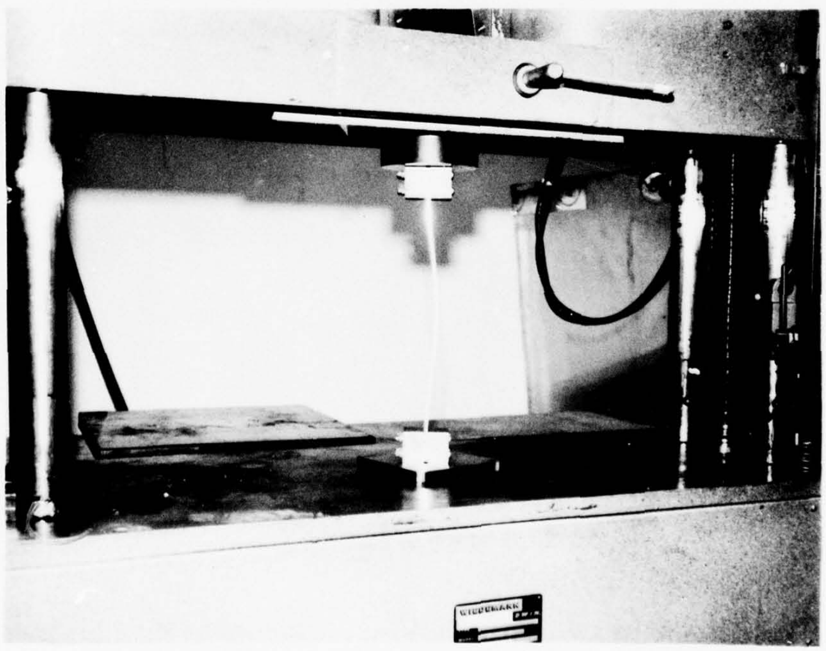
Two methods of monitoring the resulting strain were used, (1) by strain gages bonded to each side of the coupon and (2) by use of an extensometer.

The strain gage method, during the room temperature part of the test, used "BLH Electronics, Inc." strain gages, number FAP-12-12 5-6. The gages were attached to the coupons with SA-4 cement and then coated with "Viton" water proofing. During the elevated temperature part of the test "Micro Measurement" strain gages, WK-05-125BB-350, were attached to the coupons with "M-BOND 600" adhesive. The 3-wire leads of these gages were connected by silver-soldering.



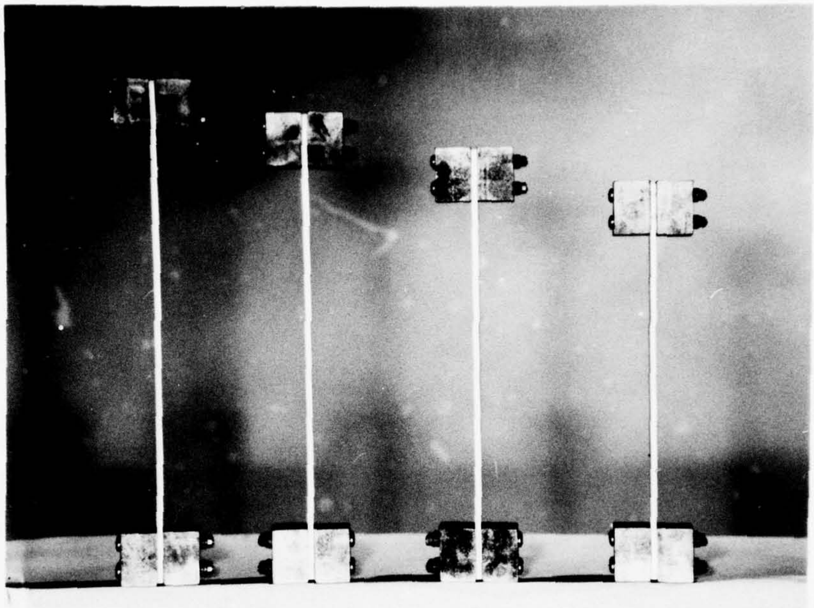
76-5221-1

FIGURE 4-4. COLUMN TEST SET-UP (ROOM TEMPERATURE)



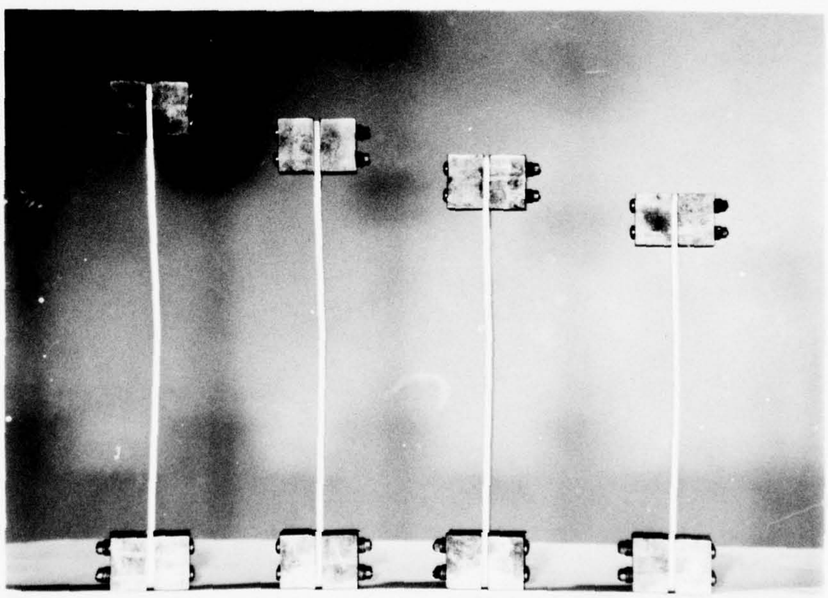
76-5221-2

FIGURE 4-5. TYPICAL COLUMN TEST SPECIMEN AFTER FAILURE



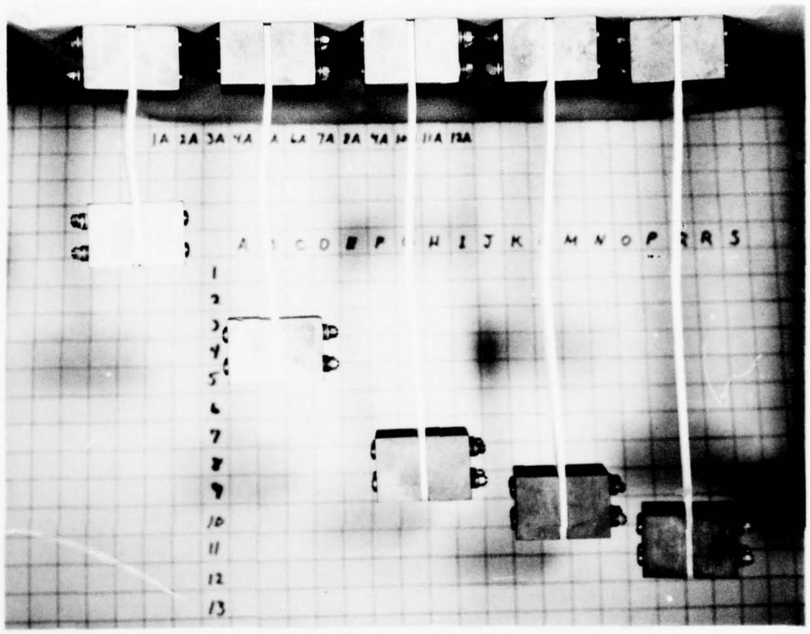
76-5221-4

FIGURE 4-6. TYPICAL COLUMN TEST SPECIMENS BEFORE TESTING.



76-5221-3

FIGURE 4-7. COLUMN TEST SPECIMENS AFTER FAILURE AT ROOM TEMPERATURE.



76-5221-6

FIGURE 4-8. COLUMN TEST SPECIMENS AFTER FAILURE AT 600°F.

TABLE 4-II - Summary of Column Test Results at Room Temp. and 600°F of Be-38Al Lockalloy - Sheet No.'s HC348-1 and HC409-3

Specimen No.	Sheet Number	Test Temp. °F	L	$L' = L/2$ (1)	$t \times w = A$	$\rho = .289t$	L'/ρ	$F_{c_{DESIGN}}$ ksi (3)	P_{FAIL} LBS	$F_{c_{FAIL}}$ ksi	M.S. (4)
1-1	HC348-1	R.T.	11.15	5.755	.156 x 1.50 = .234	.0451	123.6	11.1	3250	13.9	+.25
2-1	HC348-1	R.T.	10.15	5.075	.156 x 1.50 = .234	.0451	112.5	12.4	3650	15.6	+.26
3-1	HC348-1	R.T.	9.13	4.565	.155 x 1.50 = .232	.0448	101.9	13.6	3755	16.2	+.19
4-1	HC348-1	R.T.	8.13	4.065	.154 x 1.50 = .231	.0445	91.3	15.2	4125	17.9	+.18
6-1	HC348-1	R.T.	5.39	2.690	.155 x 1.50 = .232	.0448	60.0	22.1	6050	26.1	+.18
5-1	HC348-1	R.T.	2.62	--(2)	.156 x 1.50 = .234	.0451	--(2)	--(2)	--(2)	--(2)	--(2)
2-2	HC348-1	600	10.14	5.07	.156 x 1.50 = .234	.0451	112.5	11.5	3095	13.2	+.13
3-2	HC348-1	600	9.13	4.565	.155 x 1.50 = .232	.0448	101.9	12.4	3075	13.2	+.065
4-2	HC348-1	600	8.14	4.07	.154 x 1.50 = .231	.0445	91.5	13.0	3160	13.7	+.054
6-2	HC348-1	600	5.42	2.71	.156 x 1.50 = .234	.0451	60.1	16.5	5200	22.2	+.34
5-2	HC348-1	600	2.65	1.325	.155 x 1.50 = .232	.0448	29.6	20.0	6100	26.3	+.31
1-1	HC409-3	R.T.	11.12	5.560	.160 x 1.50 = .240	.0462	120.3	11.5	3030	12.6	+.096
2-1	HC409-3	R.T.	8.15	4.075	.161 x 1.50 = .242	.0465	87.6	16.0	4785	19.8	+.238
3-1	HC409-3	R.T.	5.42	2.710	.162 x 1.50 = .243	.0459	57.9	22.8	6450	26.5	+.162
4-1	HC409-3	R.T.	2.63	1.315	.159 x 1.50 = .233	.0460	28.6	39.1	8950	37.6	-.051
1-2	HC409-3	600	11.20	5.600	.160 x 1.50 = .240	.0462	121.2	10.6	2515	10.5	-.009
2-2	HC409-3	600	8.14	4.070	.161 x 1.50 = .242	.0465	87.5	13.5	3595	14.8	-.096
3-2	HC409-3	600	5.40	2.700	.162 x 1.50 = .243	.0468	57.5	16.6	5175	21.3	+.283
4-2	HC409-3	600	2.63	1.315	.160 x 1.50 = .240	.0462	28.5	20.0	5625	23.4	+.170

(4) MS (Margin of Safety) = $\frac{F_{c_{FAIL}}}{F_{c_{DESIGN}}} - 1$

(3) Based on ADP design data.

(2) Invalid Test - Specimen Slipped.

NOTES: (1) $L' = L/\sqrt{c}$, c = 4.

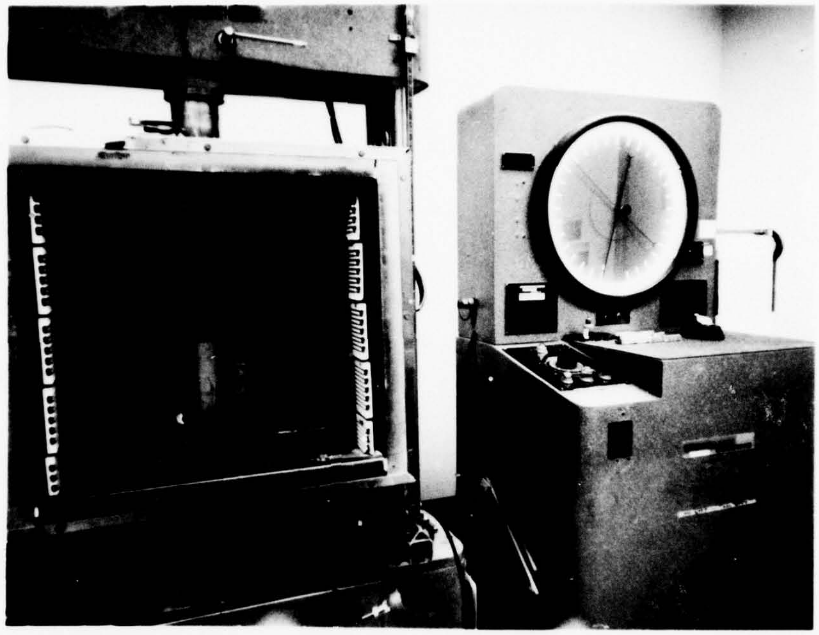


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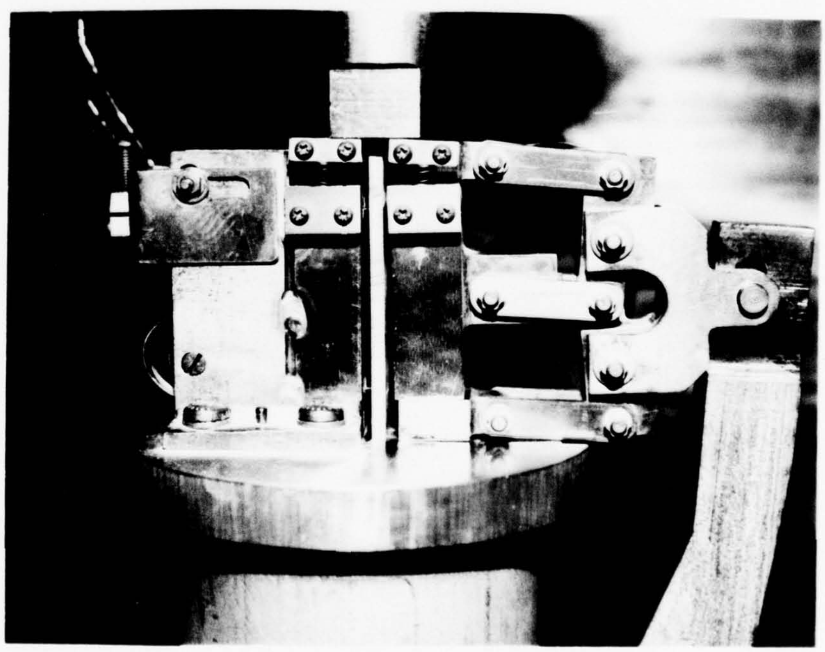
Fig. 4-10 - Overall view of test machine, furnace and compression fixture with specimen installed.



75-5405-4

Fig. 4-11 - Close-up view of compression fixture showing method of clamping specimen.

The strain gages on each specimen were connected into a full bridge network to give a double axial strain output with bending cancellation. The bridge output was connected through a balancing potentiometer to an x-y plotter to obtain loading-strain curves.

The other method of monitoring the compression strain was by an extensometer that was incorporated into the holding fixture (Fig. 4-11). The extensometer is wired directly into the Baldwin recorder and transmits strain signals produced over a two inch gage length which is centered on the specimen. A graphical determination was then made to obtain the compressive modulus (E_c), compressive yield at .2% off-set (F_{cy}) and .70 secant and .85 secant modulii. The Ramberg-Osgood shape parameter (n) was then calculated and recorded.

Testing of specimens were made at room temperature and 600°F.

A summary of material properties for these compression tests, as obtained by strain gages and by an extensometer, is shown in Table 4-III.

Tensile Tests

Tensile tests were conducted according to standard ASTM E111-61 practices. Tensile specimens of a pin loaded, two-inch gage length configuration (see Figure 4-3) were installed in a 30,000 lb Baldwin Testing Machine. A photograph of the general set-up is shown in Figure 4-12.

Strain gages and an extensometer were used to measure the resulting tension strain. The actual set-up and method of attachment of the strain gages to the coupons is the same as used for the "Compression Tests" and is described in detail on page

TABLE 4-III

SUMMARY OF COMPRESSION DATA AS OBTAINED BY EXTENSOMETERS AND STRAIN GAGES FOR Be-38Al LOCKALLOY AT ROOM TEMP. AND 600°F

$t \approx .16$ TRANSVERSE DIRECTION

	EXTENSOMETER DATA (1)						STRAIN GAGE DATA (2)					
	ROOM TEMP.			600°F			ROOM TEMP.			600°F		
SHEET NUMBER	F_{cy} ksi	E_c psi x 10^6	n	F_{cy} ksi	E_c psi x 10^6	n	F_{cy} ksi	E_c psi x 10^6	n	F_{cy} ksi	E_c psi x 10^6	n
HC348-1-1	36.8	28.8	4.1	26.0	17.7	6.5	38.0	27.4	3.4	29.0	21.5	5.5
HC348-1-2	36.4	28.6	4.0	25.9	17.0	4.9	37.4	26.7	3.5	27.0	21.4	5.7
HC348-1-3	37.1	29.1	3.5	26.0	18.9	4.3	36.2	27.1	3.4	27.6	20.3	5.8
HC348-1-4	37.7	25.5	5.0	25.9	21.2	6.4	37.1	26.9	3.7	27.3	22.8	5.0
AVERAGE	37.0	28.0	4.2	26.0	18.7	5.5	37.2	27.0	3.5	27.7	21.5	5.5
HC409-3-1	34.5	24.4	3.4	24.2	18.5	6.6	33.1	28.4	4.0	24.5	24.0	- (3)
HC409-3-2	33.8	26.8	3.9	23.7	18.8	5.3	33.4	29.5	3.8	24.8	25.8	4.4
HC409-3-3	33.2	26.7	4.4	23.1	17.7	6.4	34.5	28.5	3.6	24.9	22.1	4.5
							33.6	28.4	3.8	24.2	25.2	4.9
AVERAGE	33.8	26.0	3.9	23.7	18.3	6.1	33.6	28.7	3.8	24.6	23.7	4.6

(3) BAD CURVE.

(2) REF. R.N. PAGES 568653 AND 568664

NOTES: (1) REF. R.N. PAGES 568652 AND 568662

Views of the extensometer set-up for room temperature tests are shown in Figure 4-13 and for 600°F temperature tests in Figure 4-14.

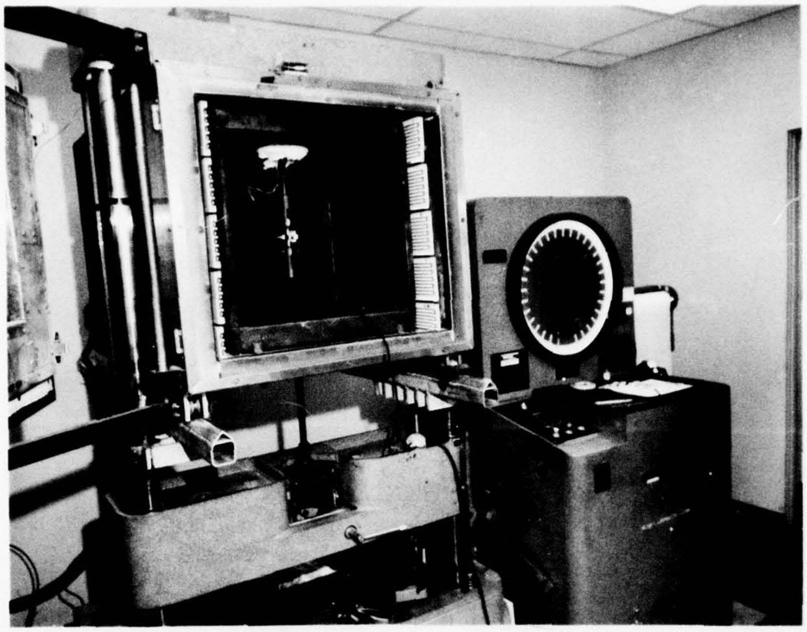
Tensile test specimens were loaded at a constant head travel rate of .005 inch/per/inch/per/minute through approximately .02 inch strain on an autographic load-strain curve. A graphical determination was then made to obtain the tensile modulus (E), tensile yield at .2% off-set (F_{ty}) and tensile ultimate (F_{tu}). Coupons were tested at room temperature and at 600°F, using the strain gages and extensometer to monitor strains induced in the respective coupons.

A summary of material properties as obtained by strain gages and by the extensometer for this tensile test is shown in Table 4-IV.

CONCLUSIONS OF COLUMN, COMPRESSION AND TENSILE TESTS

1. In an effort to establish the most reliable and accurate method of measuring the mechanical properties of Lockalloy, both strain-gages and extensometers were used for this test series. The data obtained from strain gages was considered to be more consistent and reliable. The strain-gages were chosen over the extensometers because (1) strain gage data showed less overall scatter than extensometer data, (2) the strain gage pickup is inherently more accurate than that of an extensometer and (3) strain gage data reduction requires less of an objective graphic interpretation by the technician than that obtained with an extensometer. This is due to difficulty in establishing a tangent to the small straight-line portion of the load-deflection curve, which is characteristic for the Lockalloy material.

Comparison of the compression modulus data obtained from strain-gages versus extensometers is shown in Table 4-V.



75-5354-6

Fig. 4-12 - Overall view of a typical room temperature tensile test. All room temperature tests were conducted with the furnace in place but not operating.

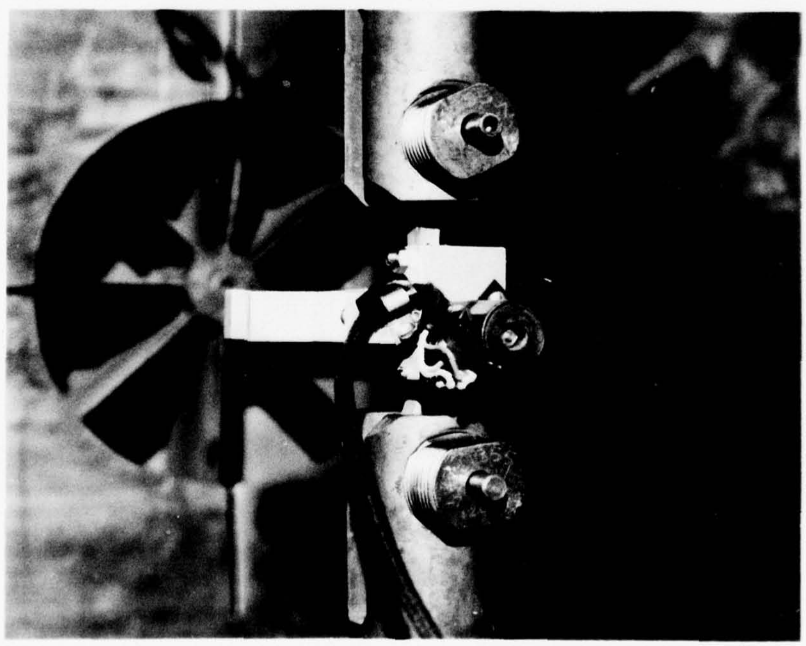


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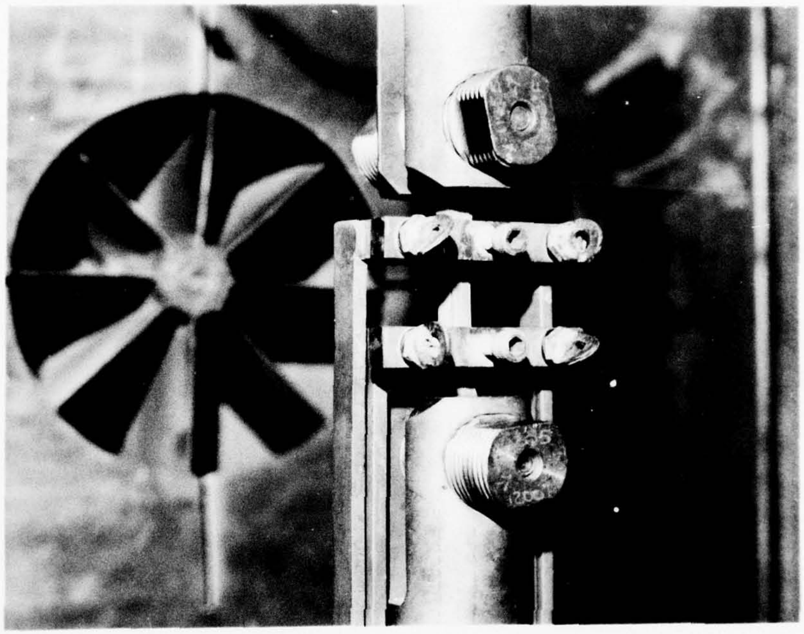
Fig. 4-13 - Close-up view of the Model B3M tensile extensometer installed on a specimen before test.



75-5354-2

Fig. 4-14 - View showing method of attachment of the Model PSH8 elevated temperature extensometer on a test specimen before test.

TABLE 4-IV

SUMMARY OF TENSION DATA AS OBTAINED BY EXTENSOMETERS AND STRAIN GAGES FOR Be-38Al LOCKALLOY AT ROOM TEMP. AND 600°F

$t \approx .16$ TRANSVERSE DIRECTION

	EXTENSOMETER DATA(1)								STRAIN GAGE DATA(2)							
	ROOM TEMP.				600°F				ROOM TEMP.				600°F			
SHEET NUMBER	F_{tu} ksi	F_{ty} ksi	e-%	E psi x 10^6	F_{tu} ksi	F_{ty} ksi	e-%	E psi x 10^6	F_{tu} ksi	F_{ty} ksi	e-%	E psi x 10^6	F_{tu} ksi	F_{ty} ksi	e-%	E psi x 10^6
HC348-1-1	52.3	40.8	8.0	27.2	25.6	23.8	6.0	17.7	52.3	38.7	8.5	28.9	26.8	24.4	-(3)	20.4
HC348-1-2	54.0	40.3	11.0	27.5	25.7	24.1	5.5	17.3	52.5	40.0	8.5	30.6	27.1	25.1	-	21.2
HC348-1-3	51.7	39.6	10.0	26.8	25.4	24.3	5.0	20.5	53.6	39.5	11.0	30.3	27.2	25.2	-	20.9
AVERAGE	52.7	40.2	9.7	27.2	25.6	24.1	5.5	18.5	52.8	39.4	9.3	29.9	27.0	24.9	-	20.8
HC409-3-1	51.7	36.6	9.0	26.4	22.9	21.3	8.5	20.2	51.4	36.9	8.5	28.8	23.8	21.9	5.5	22.3
HC409-3-2	51.5	36.6	9.0	25.3	24.2	22.1	6.0	18.7	51.2	36.6	8.5	28.1	24.3	22.8	6.5	22.0
HC409-3-3	52.1	37.9	9.5	24.6	24.3	22.6	7.5	20.0	51.1	35.3	10.0	28.8	23.9	22.0	5.5	22.4
AVERAGE	51.8	37.0	9.2	25.4	23.8	22.0	7.3	19.6	51.2	36.3	9.0	28.6	24.0	22.2	5.8	22.2

(3) GAGE LENGTH NOT MARKED PRIOR TO LAYING STRAIN GAGES

(2) REF. R.N. PAGES 568659 AND 568991.

NOTES: (1) REF. R.N. PAGES 568655 AND 568660.

2. Analysis of the column test data indicate that the methods currently used to predict column allowables for other structural materials apply equally to Lockalloy material. Column failure test datapoints are plotted with the predicted column stress curve corrected to reflect the actual mechanical properties of each Lockalloy sheet from which the test coupons were fabricated. See Figures 4-15 thru 4-18. A comparison shows that the actual column failure stress data points do correlate with predicted column allowable curves generated by methods currently used (Stress Memo 80) for other structural materials. This correlation is shown numberically in the "Summary of Margin of Safety" calculations, Table 4-VI.

Both the figures of column curve graphs and the margin of safety summary include design allowable data for reference comparison.

3. As the result of testing strain-gaged tensile and compressive test specimens, the following modulii at room temperature and 600°F are recommended for Be-38Al Lockalloy:

Modulus	Room Temp.	600°F
E, 10^6 psi	28.0	*20.0
E_C, 10^6 psi	27.0	*22.0

*Only the modulus for 600°F have been revised from current design allowables for Lockalloy.

TABLE 4-V

COMPARISON OF COMPRESSION MODULUS DATA AS OBTAINED BY STRAIN GAGE VERSUS EXTENSOMETER FOR TWO SHEET NUMBERS OF Be-38Al LOCKALLOY AT R.T. AND 600°F

	COMPRESSION MODULUS, E_c - psi x 10^6							
TYPE INSTRU.	STRAIN GAGE DATA				EXTENSOMETER DATA			
SHEET NUMBER	HC348-1		HC409-3		HC348-1		HC409-3	
REF. R.N. PAGE	568653		568664		568652		568662	
TEST TEMP / COUPON	R.T.	600°F	R.T.	600°F	R.T.	600°F	R.T.	600°F
-1	27.4	21.5	28.4	24.0	28.8	17.7	24.4	18.5
-2	26.7	21.4	29.5	25.8	28.6	17.0	26.8	18.8
-3	27.1	20.3	28.5	22.1	29.1	18.9	26.7	17.7
-4	26.9	22.8	28.4	23.2	25.5	21.2	-	-
AVERAGE	27.0	21.5	28.7	23.7	28.0	18.7	26.0	18.3

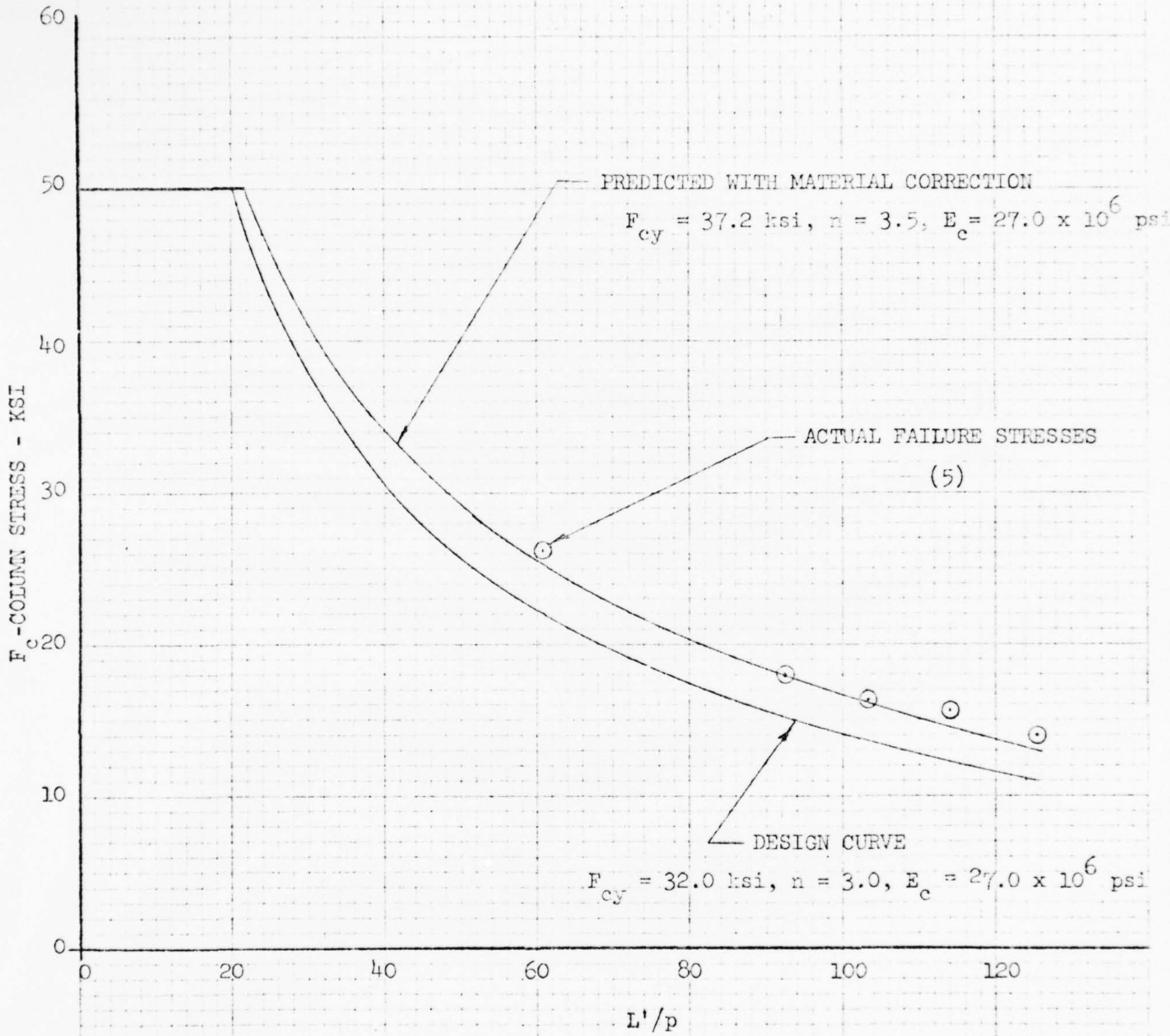


FIG. 4-15 - COLUMN TEST AT ROOM TEMP.
Be-38Al LOCKALLOY (Annealed)
SHEET NUMBER HC348-1.

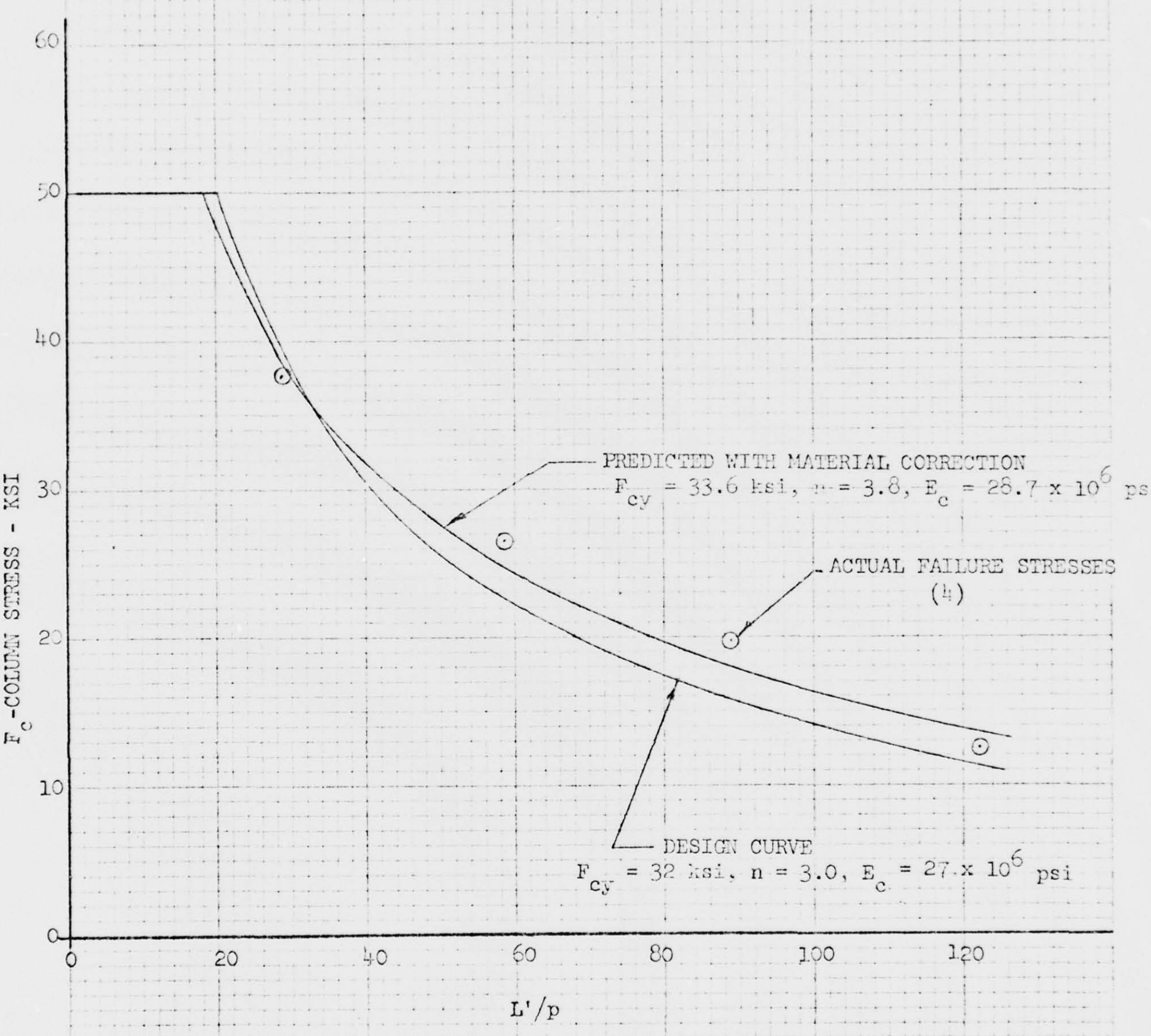


FIG. 4-16 - COLUMN TEST AT ROOM TEMP.
Be-38Al LOCKALLOY (Annealed)
SHEET NUMBER HC409-3

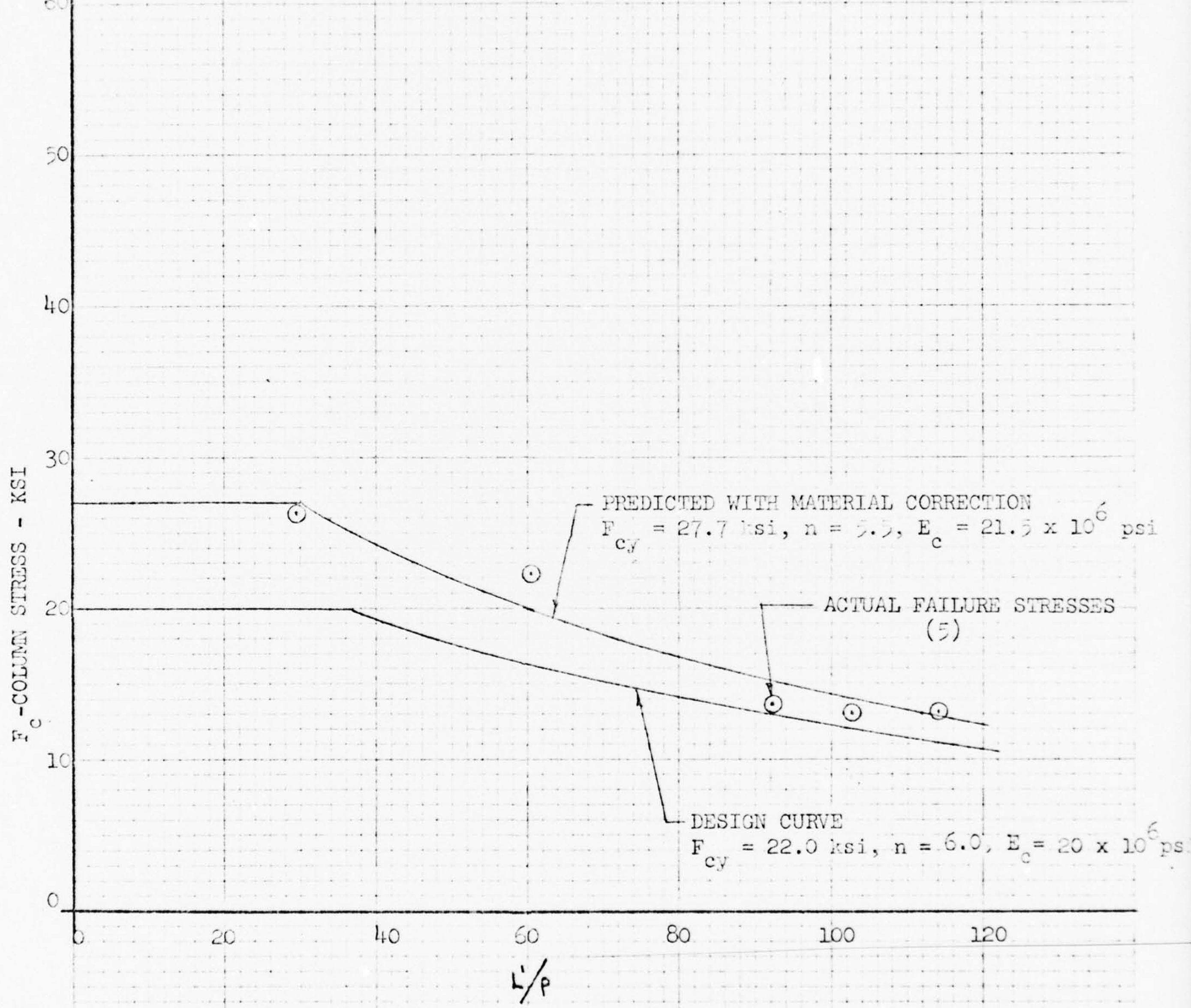


FIG. 4-17 - COLUMN TEST AT 600°F
Be-38Al LOCKALLOY (Annealed)
SHEET NUMBER HC348-1

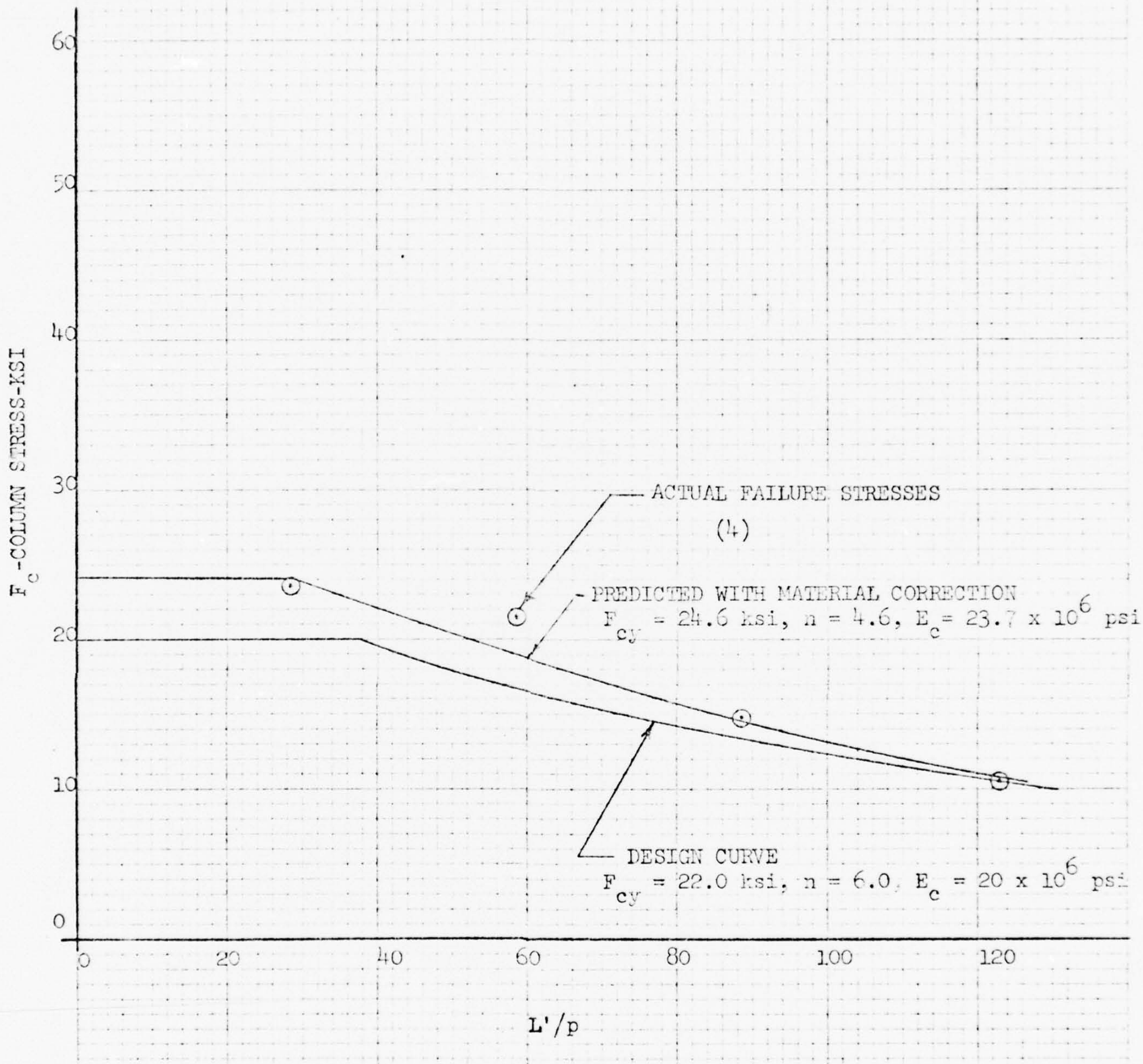


FIG. 4-18 - COLUMN TEST AT 600°F
Be-38Al LOCKALLOY (Annealed)
SHEET NUMBER HC409-3.

TABLE 4-VI - SUMMARY OF MARGIN OF SAFETY (MS) FOR LOCKALLOY COLUMN TEST SPECIMENS

TEMP.	Be-38Al SHEET	L'/P	A F_c EXISTING DESIGN ALLOWABLES	B F_c ACTUAL COLUMN FAIL STRESS	C F_c ALLOWABLE PREDICTED W/MAT'L CORRECTION	$M.S. = \frac{B}{A} - 1$	$M.S. = \frac{B}{C} - 1$
ROOM TEMP.	HC348-1	123.6	11.1	13.9	12.9	+ .25	+ .078
		112.5	12.4	15.6	14.5	+ .26	+ .076
		101.9	13.6	16.2	16.0	+ .19	+ .012
		91.3	15.2	17.9	17.8	+ .18	+ .006
		60.0	22.1	26.1	25.1	+ .18	+ .040
	HC409-3	120.3	11.5	12.6	13.5	+ .096	- .067
		87.6	16.0	19.8	17.9	+ .238	+ .106
		57.9	22.8	26.5	24.8	+ .162	+ .068
		28.6	39.1	37.6	38.5	- .051	- .023
600^oF	HC348-1	112.5	11.5	13.2	13.1	+ .13	+ .008
		101.9	12.4	13.2	14.0	+ .065	- .057
		91.5	13.0	13.7	15.3	+ .054	- .105
		60.1	16.5	22.2	19.9	+ .34	+ .116
		29.6	20.0	26.3	27.0	+ .31	- .026
	HC409-3	121.2	10.6	10.5	10.9	- .009	- .037
		87.5	13.5	14.8	14.4	+ .096	+ .028
		57.7	16.6	21.3	18.9	+ .283	+ .127
		28.5	20.0	23.4	24.0*	+ .170	- .025

$^*F_{tu}$ = 24.0 CUTOFF

SECTION 5

THERMAL TREATMENT OF Be-38Al LOCKALLOY

OBJECTIVE

To evaluate the effects, if any, of various thermal treatments on the mechanical properties of as-received Be-38Al Lockalloy sheet.

SUMMARY OF RESULTS

Five tension specimens prepared from a sheet of 0.150 Be-38Al Lockalloy sheet were each subjected to different thermal treatments and their mechanical properties compared to those of an "as-received" specimen prepared from the same sheet of material.

The very limited, single-point data obtained from these specimens tends to indicate that the mechanical properties (in particular, the proportional limit) of as-received Lockalloy sheet might be increased by an appropriate thermal treatment. The magnitude of the increases obtained was quite small, however, and, in the absence of additional data, must be considered to be within the normal test scatter of mechanical properties for this material.

BACKGROUND

For certain applications, a post-manufacturing thermal treatment (solution treat, sub-zero quench, and artificial age) has been used to increase the proportional limit and yield strength of as-fabricated boron-aluminum (6061 alloy) metal matrix composites. It has been theorized that the large difference in thermal coefficient of expansion between the boron filaments and aluminum matrix material induces high residual stresses in the aluminum as the composite cools from the diffusion bonding or consolidation temperatures. Apparently these residual stresses are partially relieved by a solution treat and sub-zero quench. The

increase in proportional limit and yield strength have been attributed to the combined effects of this reduction in residual stress and the subsequent age response of the 6061 aluminum alloy matrix.

Be-38Al Lockalloy has a relatively low proportional limit (approximately 10,000 psi) compared to other structural materials of equal strength. Since Lockalloy is a particulate composite consisting of interlocking matrices of pure aluminum and beryllium, which also have significantly different coefficients of expansion, it was postulated that some form of thermal treatment, similar to that used on the filamentary metal matrix composites, might produce a similar increase in proportional limit. The very limited study described herein was undertaken to investigate this possibility. No effect on yield strength was anticipated since pure aluminum (unlike the 6061 alloy) can not be strengthened by thermal treatment.

DESCRIPTION OF TEST SPECIMENS

Six, two-inch gage length, transverse-grain tensile specimens, of the configuration shown in Figure 5-1, were prepared from a remnant of 0.150 inch Be-38Al Lockalloy sheet (Kawecki Berylco Industries, Inc., Sheet No. HC-243-1). These specimens were identified D939-1T through -6T. The -1T specimen was to be tested in the as-received condition to establish a basis for comparison. Prior to testing, the -2T through -6T specimens were subjected to the thermal treatments indicated below:

Specimen Number	Thermal Treatment
D939-2T	$-100^{\circ}F$ (2 hrs.)
-3T	$-320^{\circ}F$ (2 hrs.)
-4T	$1100^{\circ}F$ (20 min.); Water Quench; $-100^{\circ}F$ (2 hrs.)
-5T	$1100^{\circ}F$ (20 min.); Water Quench; $-320^{\circ}F$ (2 hrs.)
-6T	$1100^{\circ}F$ (20 min.); Water Quench; $-100^{\circ}F$ (2 hrs.); $350^{\circ}F$ (6 hrs.)

TEST PROCEDURE

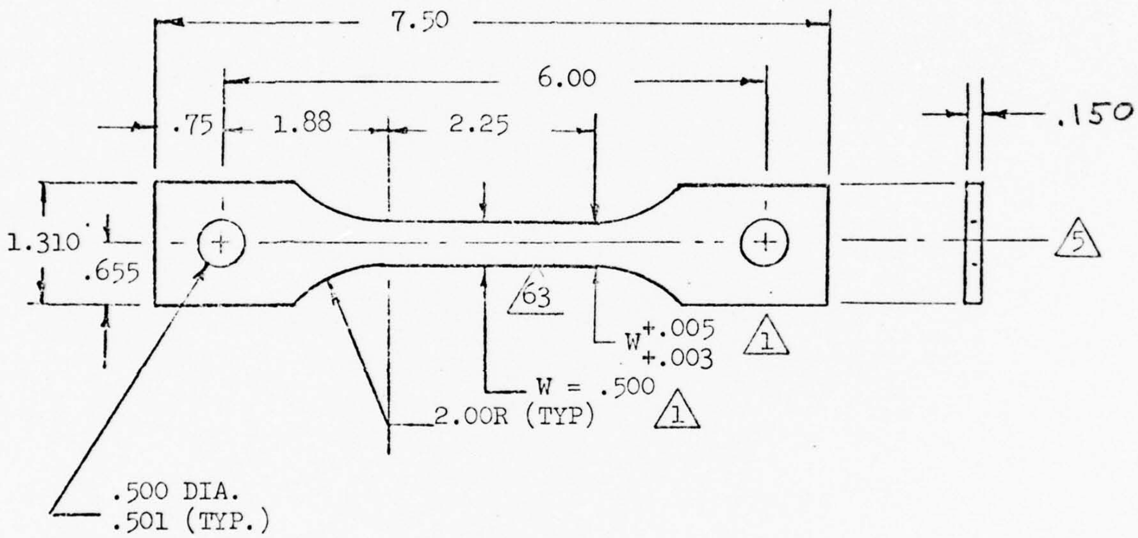
All specimens were tested to failure at room temperature in a 30,000 lb. capacity Baldwin Mark B Universal Test Machine. The specimens were loaded at a constant strain rate of 0.005 in./in./min. A Wiedeman TIM-1081, two-inch gage length extensometer and a load-strain recorder were used to obtain autographic load-strain curves. Expanded load and strain scales were used on initial loading to more accurately establish initial deviation from the straight line portion of the load-strain curve and define the proportional limit. The load and strain scales on the recorder were then contracted (without unloading the specimen) and loading continued until the specimen failed.

TEST RESULTS

The mechanical properties obtained for these test specimens are given in Table 5-I.

CONCLUSIONS

The proportional limits reported for the specimens which had been subjected to $1100^{\circ}F$ for 20 min. followed by a water quench, and a sub-zero quench at $-100^{\circ}F$ (-4T) or $-320^{\circ}F$ (-5T) for 2 hrs. were, respectively, 22.5 and 25.5 percent higher than that of the as-received specimen (-1T). While these would appear to be



NOTE: 1 RADIUS FROM ENDS OF REDUCED SECTION TO CENTER

2. SCALE 1/2

3. USE FOR ELEVATED TEMPERATURE TESTS

4. LEAVE ALL EDGES SHARP

5 SYMMETRICAL TOLERANCE $\pm$.001

Figure 5-1 - Tension Specimen, Two-Inch Gage Length

Table 5-I - Mechanical Properties of Be-38AL Lockalloy Sheet after Various Thermal Treatments[1]

Specimen Number	F_{tu} (ksi)	F_{ty} (ksi)	e (% in 2 in.)	E_T (psi x 10^{-6})	Proportional Limit (ksi)
D939-1T[2]	50.3	35.0	11.0	27.8	10.6
-2T	49.1	34.2	8.5	30.3	11.8
-3T	50.1	34.3	11.0	27.0	9.3
-4T	52.8	35.0	12.0	29.0	13.0
-5T	52.6	35.4	11.5	27.3	13.3
-6T	52.5	35.2	15.0	28.0	12.0

(1) Reference: Research Notebook Page No. 568685

(2) Tested in the as-received condition

significant increases, the actual values of 13.0 and 13.3 ksi are still quite low with respect to ultimate tensile strength. Also, on the basis of this very limited test data, it is difficult to conclude that the indicated increases are actually the result of the thermal treatments. They may have been the result of normal test scatter for this material and/or inherent testing inaccuracies. Even though specialized load-strain recording techniques were used during these tests, the point of initial deviation from the straight line portion of the curve (proportional limit) is very difficult to establish without using strain-gaged specimens.

If, in a particular application, the low proportional limit of Lockalloy would result in a significant weight penalty, a more thorough investigation of the effects of various thermal treatments on the mechanical properties of Be-38Al sheet may be warranted. The added costs of any such thermal treatments on a production basis would, of course, also be an important consideration in evaluating the benefits of any potential improvement in mechanical properties.

SECTION 6

NOTCHED BAR (CHARPY) IMPACT TEST

OBJECT

To determine and compare the Charpy impact strength of Be-38Al Lockalloy to other structural materials when subjected to a single application of load at room temperature.

SUMMARY

Quantitative charpy impact tests on various structural materials indicate that Be-38Al Lockalloy has an impact strength exceeding that of PS-20 Beryllium and approaching that of 7075-T6 aluminum.

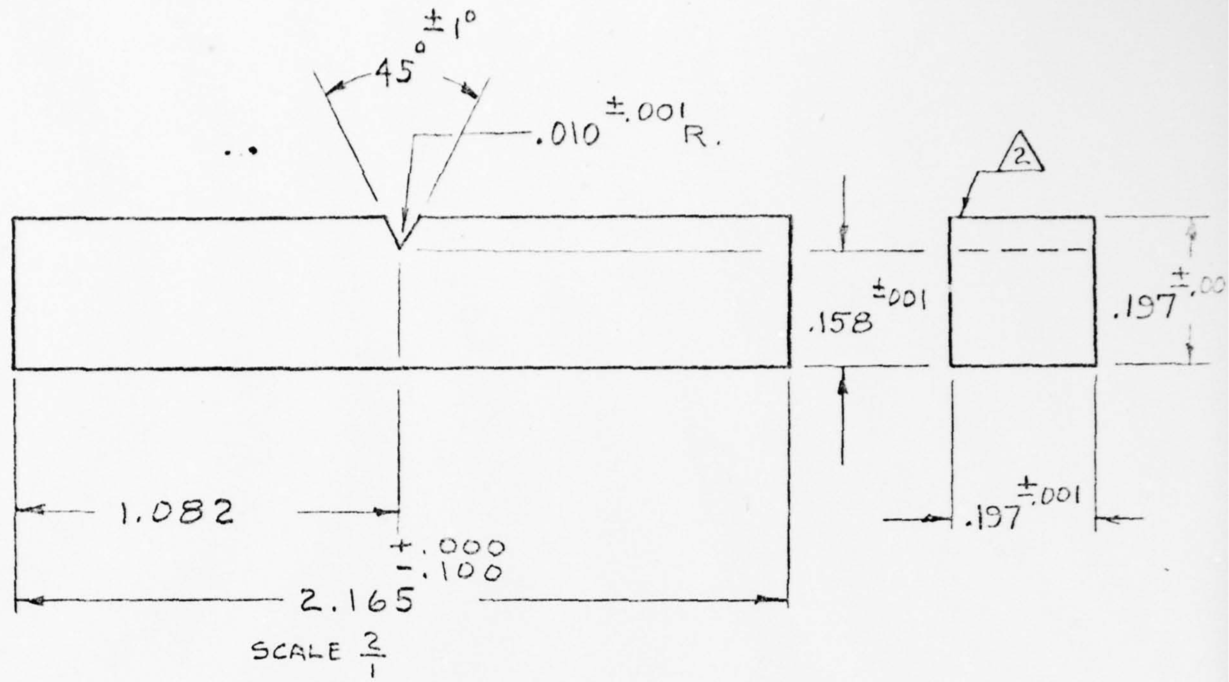
TEST PROCEDURE

Impact tests were conducted according to standard ASTM E23-72 practices. Testing was performed by "Atlas Testing Laboratories, Inc.," Los Angeles, California. Test coupons (see figures 6-1 and 6-2) having a cross-section of .197 in. x .197 in., with a type "A" configuration (ASTME23-72) notch, in the longitudinal, long transverse and short transverse directions were impact tested at 72°F. The various coupon materials tested include Be-28Al Lockalloy, 7075-T6 Aluminum, PS-20 Beryllium, 2024-T351 Aluminum, 4130 Steel (H.T. 125 ksi), 5Al-2.5Sn Titanium, Annealed 6Al-4V Titanium, and Aged 13V-11Cr-3Al Titanium. Three (3) coupons for each grain direction were tested for all materials investigated.

TEST RESULTS

Table 6-I lists the impact test results for all the materials tested. A summary of the average impact strength values for each material is shown in Table 6-II and graphically prsented in Figure 6-3.

The notch behavior indicated in an individual test applies only to the specimen size, notch geometry, and testing conditions involved and cannot be generalized to other sizes of specimens and conditions. These energy values cannot be converted into values that would serve for engineering design calculations, but do offer a comparative evaluation of the impact strength of the materials tested.



NOTE: 1. 63 all surfaces and notch.

2 all edges to be flat, square, and parallel.

3. Leave all edges sharp.

4. Out of square -.001 inch in .197 inch.

Figure 6-1 - Impact Test Specimen

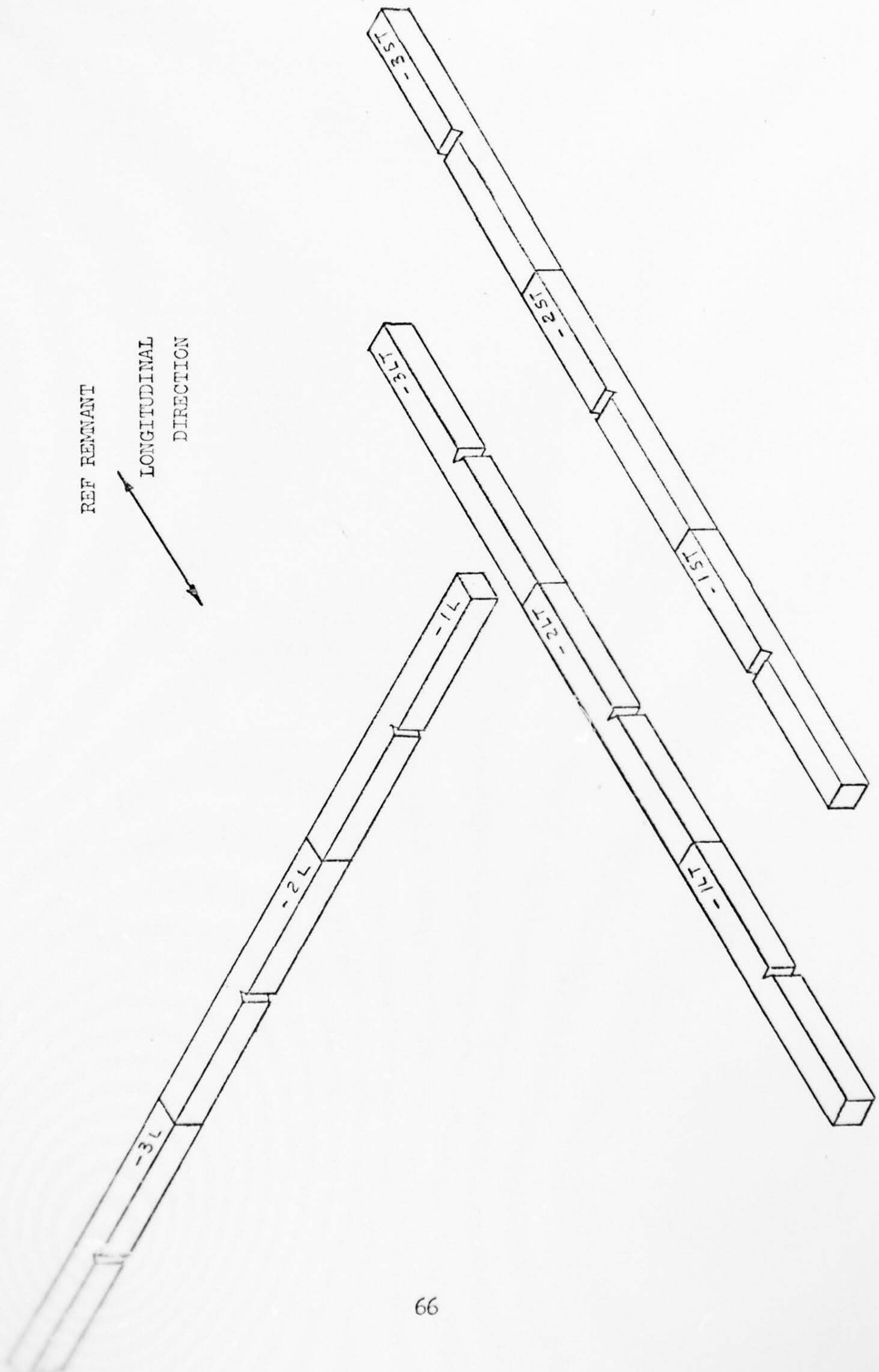


FIGURE 6-2 TYPICAL IMPACT SPECIMEN LAYOUT

TABLE 6-I - IMPACT TEST DATA

GRAIN DIRECTION - COUPON NO.	Be-38Al LOCKALLOY IN.-LBS	Be(2) PS-20 IN.-LBS	7075-T6 IN.-LBS	2024-T351 IN.-LBS	4130(H.T. 125 ksi) STEEL IN.-LBS	Ti 5Al-2.5Sn IN.-LBS	Ti 6Al-4V (Annealed) IN.-LBS	Ti 13V-11Cr -3Al (Aged) IN.-LBS
L-1	5.25	.75	8.5	12.25	61.0	27.0	47.5	16.0
L-2	5.5		8.25	16.0	58.0	28.0	38.5	12.5
L-3	5.5		8.0	12.0	60.0	26.5	43.0	17.5
LT-1	5.75		9.75	25.0	116.0	30.0	26.5	18.0
LT-2	5.75		9.5	22.5	115.0	26.5	30.5	15.5
LT-3	5.75		9.5	23.0	115.0	25.0	34.0	13.5
ST-1	6.75		11.5	16.5	72.0	40.0	38.0	30.5
ST-2	7.25		11.0	16.0	69.0	44.0	39.0	30.0
ST-3	7.25	.75	11.75	15.0	74.0	50.0	42.0	30.5

		LONG.	TRANS.
(2) BERYLLIUM PS-20 MATERIAL PROPERTIES;	F_{TU}	78,600	78,800
("KBI" #H-1855)	F_{TY}	53,000	53,300
	% ELONG	24.7	22.7

1. TYPE OF SPECIMEN: V-NOTCH "A"; SIZE: .197 x .197; TEST TEMP: 72°F

TABLE 6-II - SUMMARY OF IMPACT ENERGY AVERAGES (IN-LBS)

	Be-38Al LOCKALLOY IN.-LBS	Be(2) PS-20 IN.-LBS	7075-T6 IN.-LBS	2024-T351 IN.-LBS	4130(H.T. 125 ksi) STEEL IN.-LBS	Ti 5Al-2.5Sn IN.-LBS	Ti 5Al-4V (Annealed) IN.-LBS	Ti 13V-11Cr -3Al (Aged) IN.-LBS
(L) LONGITUDINAL	5.4	.75	8.25	13.4	59.6	27.1	43.0	15.3
(LT) LONG TRANSVERSE	5.75	.75	9.6	23.5	115.3	27.1	30.3	15.6
(ST) SHORT TRANSVERSE	7.1	.75	11.4	15.8	71.6	44.6	39.6	30.3

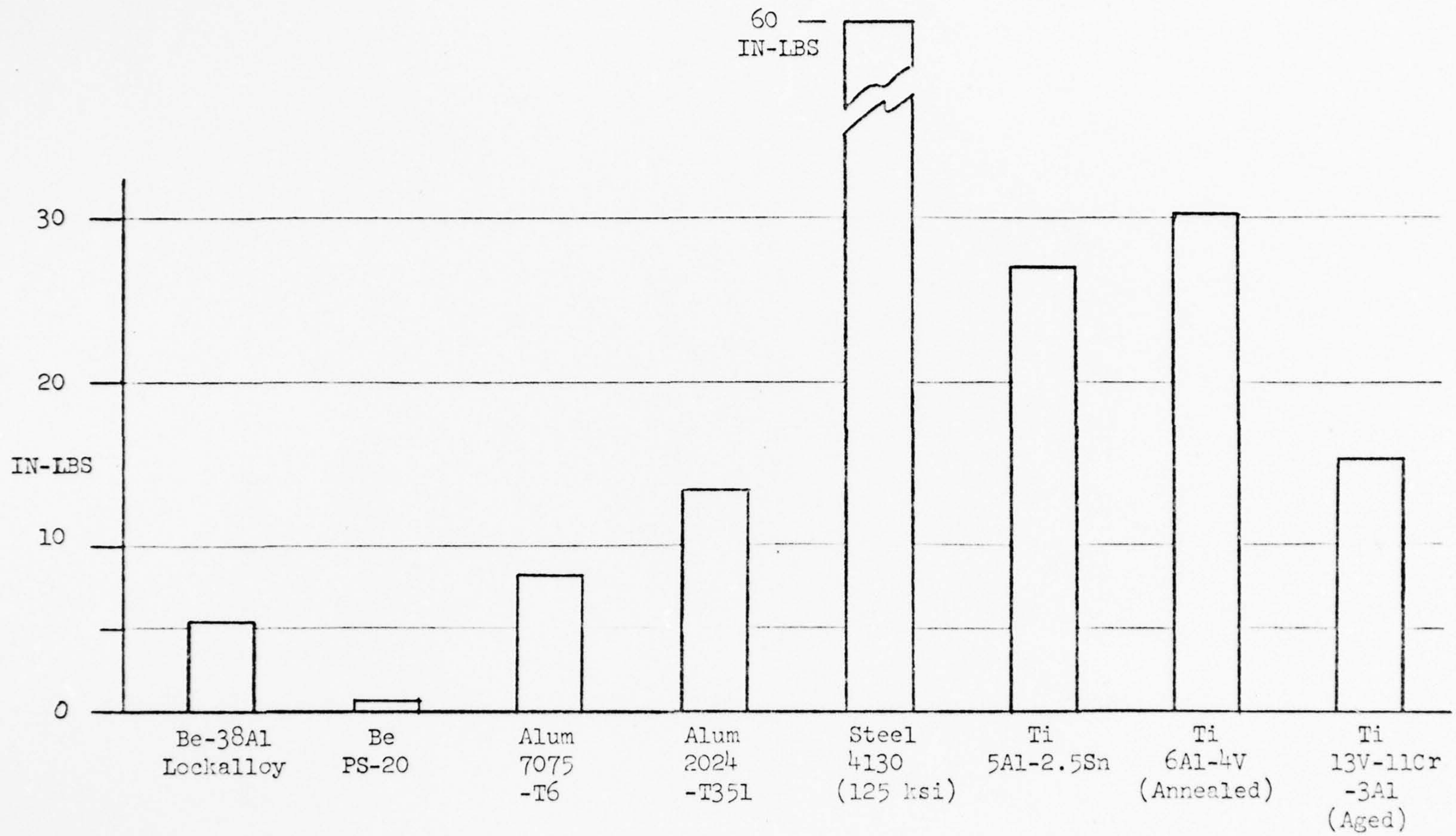


FIG. 6-3. COMPARISON OF IMPACT ENERGY FAILURE VALUES (MINIMUM AVERAGE VALUES, CONSIDERING ALL GRAIN DIRECTIONS)

SECTION 7

WELDING TESTS

OBJECT

To determine the practicality of fusion welding as a joining method for Be-38Al material.

SUMMARY

A limited number of tension, fatigue and bend tests were performed on specimens prepared from electron beam buttwelded remnants of Be-38Al Lockalloy sheets machined to .100 inch thick. On the basis of ultimate tension strength, weld joint efficiencies of approximately 80% were obtained, accompanied by a considerable reduction in elongation.

Based on the limited tests performed the fatigue life of welded Lockalloy appears to be equivalent to the fatigue strength of unwelded Lockalloy with a stress concentration factor of $K_t = 3$. Welded bend test samples failed to pass an R/t of 20 when bent across the weld.

X-ray of the weld joints showed some porosity which may have contributed to the loss in ductility and fatigue strength.

Development of the electron beam welding parameters could result in reduced porosity and increased strength, ductility and fatigue of welded joints.

WELD PROCEDURE

All welding was performed by LMSC personnel in their Hamilton-Standard 150KV 50 M.A., Model No. EBW (7.5) 108-56-56 electron beam welding machine.

Twelve Lockalloy pieces of irregular shape, varying in size from approximately 2 x 7 to 5 x 20 inches were supplied to LMSC to produce six butt-welded assemblies. The materials were remnants of various .125 and .150 inch thick sheets left over from an earlier program. All remnants had at least one edge in the "as received" machine condition which was used for the joining edge.

Preparation for welding consisted of abrasive cleaning the faying surfaces of the joint with 240 grit abrasive cloth followed by a MEK solvent wipe. After cleaning, each assembly was placed on the welding jig and clamped. The chamber was evacuated and the joint aligned with the beam. A tack weld was then made at each end of the joint.

The welding assemblies #5 and #6 were used for set-up purposes to establish welding parameters. Figure 7-1 shows a diagram of the welding set-up and Table 7-I summarizes the preliminary welding data.

Panels number 1 thru 4 were machined on both surfaces to clean-up the weld bead, weld undercut and to maintain a uniform thickness (.100 inch). Another radiograph of the weld joints were then taken. The general characteristics comparing the radiographs before and after machining the weld joint are compared on the next page.

X-RAY AFTER WELD	X-RAY AFTER CLEAN-UP MACHINING BOTH SIDES OF WELD TO .100 INCH THICK
ASSEMBLY #1 (.150 THICK)	
One spot $6\frac{1}{2}$ inches from start of weld, where beam did not fully penetrate. Some proosity.	Scattered porosity. Spot $6\frac{1}{2}$ inches from start now looks like a typical porosity spot.
ASSEMBLY #2 (.125 THICK)	
Some undercut on sides of welds. Good penetration. Some porosity.	Some porosity still visable.
ASSEMBLY #3 (.125 THICK)	
Good weld except last 3 inches where pieces were not clamped properly.	Some porosity is visable.
ASSEMBLY #4 (.125 THICK)	
Some undercut and/or lack of fusion at the edges of the weld. A slightly wider cosmetic pass is recommended.	Some porosity is visable. Lack of fusion at edges.
ASSEMBLY #5 (.125 THICK)	
Intermittent welds at various settings.	Since assemblies #5 & #6 were used only to establish weld set-up parameters no machining was performed.
ASSEMBLY #6 (.150 THICK)	
Weldment sectioned for metallographic exam.	

It is concluded that most of the porosity condition evident in the radiograph of the initial weld will be present after the weld has been machined to remove the weld bead and undercut.

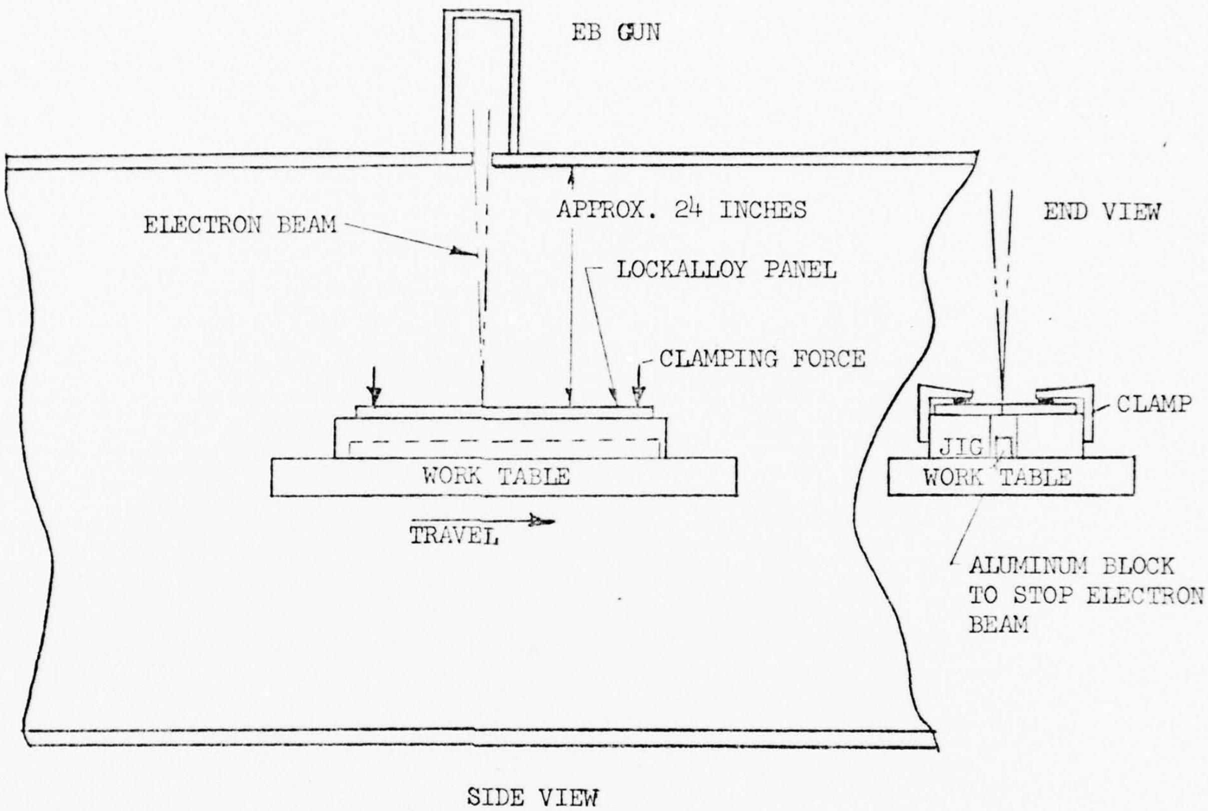


FIG. 7-1 - DIAGRAM OF ELECTRON BEAM WELDING SET-UP

TABLE 7-I

Summary of Preliminary Welding Data

Run No.	Travel Speed (ipm)	Voltage (KV)	Beam Current (m A)	Focus Location	Circle Generator Frequency (cps)	Circle Generator Circle Size (in)
Preliminary Welds - .150-inch thickness (Assembly #6)						
6-1	30	125	10	Top Surface	-	-
6-2	30	125	12	Top Surface	-	-
6-3	30	125	11	Top Surface	-	-
→ 6-4	30	125	14.5	Top Surface	7000	1/32 dia.
6-5*	20	110	10	Top Surface	7000	1/16 dia.
Preliminary Welds - .125-inch thickness (Assembly #5)						
5-1	30	125	20	Top Surface	7000	1/64 dia.
5-2	30	125	15	Top Surface	7000	1/64 dia.
5-3	30	125	11	Top Surface	7000	1/64 dia.
5-4	30	125	11	Top Surface	7000	3/128 dia.
→ 5-5	30	125	11	Top Surface	7000	1/32 dia.
5-6*	20	110	10	Top Surface	7000	1/16 dia.

*Cosmetic Pass (cleaned top of first pass with a stainless steel wire brush before placing cosmetic pass.

→ Parameters used in welding remaining test panels.

WELD TEST PROCEDURE

Panels 1, 2 and 4 were cut into test coupons. Table 7-II lists the material with respective coupon and test performed. Specific coupon drawings are shown in Figure 7-2 thru 7-5.

Tension testing was performed on nine coupons at room temperature and on three coupons at 600°F. Tension tests were conducted according to standard ASTM E111-61 practices. Yield and modulus volumes were determined graphically from the autographic load-strain curves. Extensometer measurements were utilized. Permanent deformation was determined by measuring between lightly scribed gage marks within .0002 inch.

Bend testing was performed at room temperature by a power brake on three coupons machined to .063 thickness, see Fig. 7-6. Radii of the brake forming tools used to bend the coupons were .75, 1.0 and 1.25 inches.

Roll bending was demonstrated by rolling a butt-welded remnant having an approximate size of 3 x 15 inches (Assembly #3) on a three-roller machine to a $7\frac{1}{2}$ inch radius segment. See Fig. 7-7 for picture of rolled specimen.

Fatigue tests were conducted in a 10,000 lb. Lockheed designed constant amplitude resonant fatigue machine as shown in Fig. 7-8.

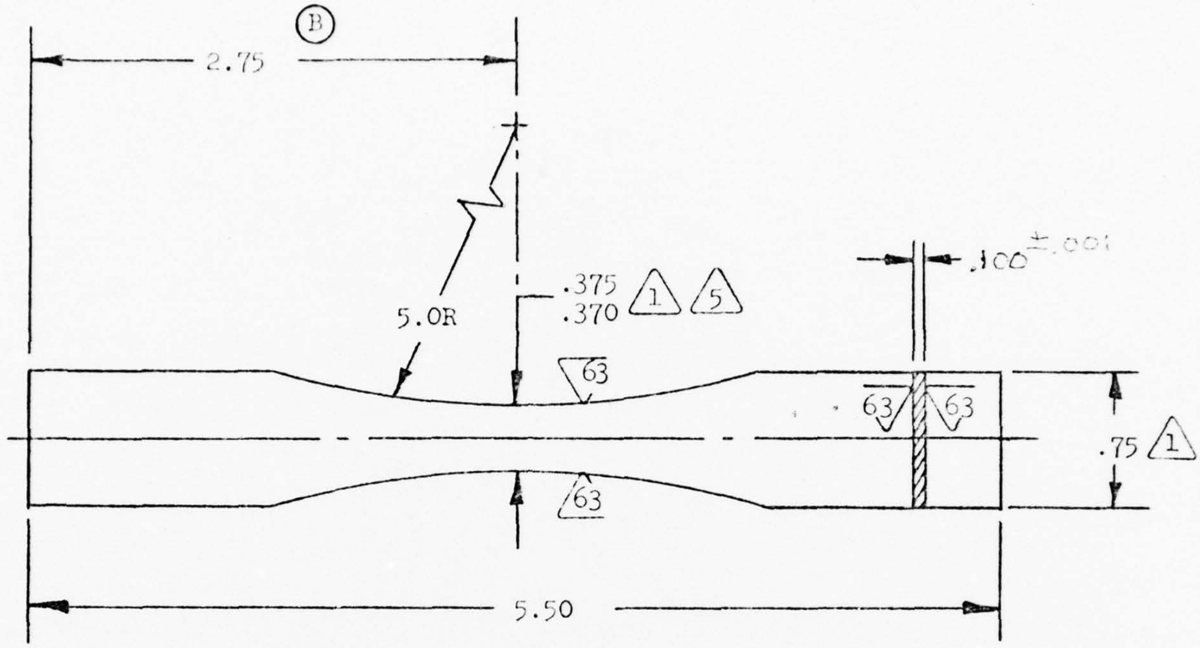
Welded fatigue coupons (Fig. 7-2) were fatigue tested at room temperature and 600°F. A close-up view of an installed coupon at room temperature is shown in Fig. 7-9.

All tests were conducted at a range ratio, R = 0.1, util failure or until 10^7 cycles were reached at which time the test was terminated. Specimens were stabilized at 600°F for 15 minutes prior to the 600°F fatigue test.

TABLE 7-II

MATERIAL AND COUPON DISTRIBUTION

Be-38Al Sheet ID (2 Halves)	Weld Assy (Thickness)	Test	Coupon No.	Ref Coupon (Fig.)
HC-161-4	#1	Tensile R.T.	TH-1-1;-2;-3	Fig. 7-3
HC-227-1	(.150)	Tensile 600°F	TH-1-4;-5;-6	Fig. 7-4
		Bend R.T.	TH-1-7;-8;-9	Fig. 7-5
HC-161-1	#2	Tensile R.T.	TH-2-1;-2;-3	Fig. 7-3
HC-227-4	(.125)	Fatigue R.T.	TH-2-4;-5;-6	Fig. 7-2
		Fatigue 600°F	TH-2-7;-8;-9	Fig. 7-2
HC-197-4	#3			
HC-197-4	(.125)	Roll Formed Entire Assembly		
HC-137-4	#4	Tensile R.T.	TH-4-1;-2;-3	Fig. 7-3
HC-137-4	(.125)			
HC-197-4	#5	Used for Weld Set-Up		
HC-137-5	(.125)			
HC-243-2	#6	Used for Weld Set-Up		
HC-227-3	(.150)			

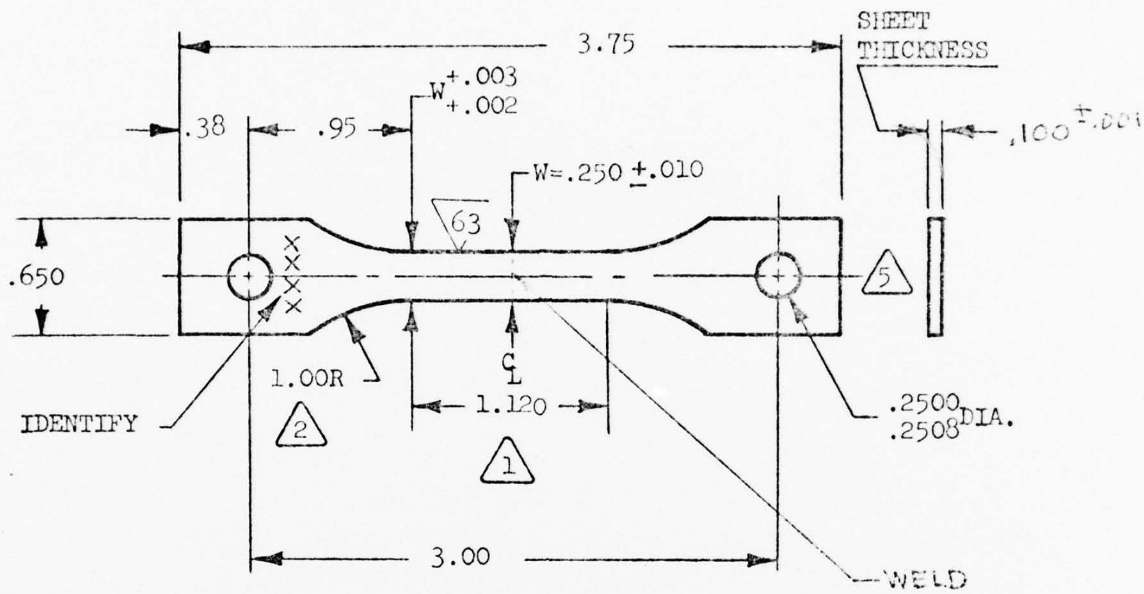


FATIGUE COUPON - UNNOTCHED

NOTE:

1. TO BE SYMMETRICAL ABOUT CENTERLINE WITHIN ±.003 INCHES (C)
2. THIS COUPON $K_t = 1.0$
3. ENDS MAY BE SHEARED, ALL OTHER SURFACES TO BE 63
4.
5. INCREASE AS REQUIRED TO MAINTAIN AREA ≥ .023 SQ/INS.

FIG. 7-2 - FATIGUE COUPON - UNNOTCHED



TENSION COUPON - 1 INCH GAGE LENGTH - SHEET

NOTE:

1. DIMENSION AT ENDS OF THIS GAGE LENGTH MUST BE LARGER BY +.002 TO +.003 INCHES THAN THE W = .250 ±.010 INCHES AT CENTERLINE. RADIUS TAPER FROM ENDS TO CENTERLINE REQUIRED.

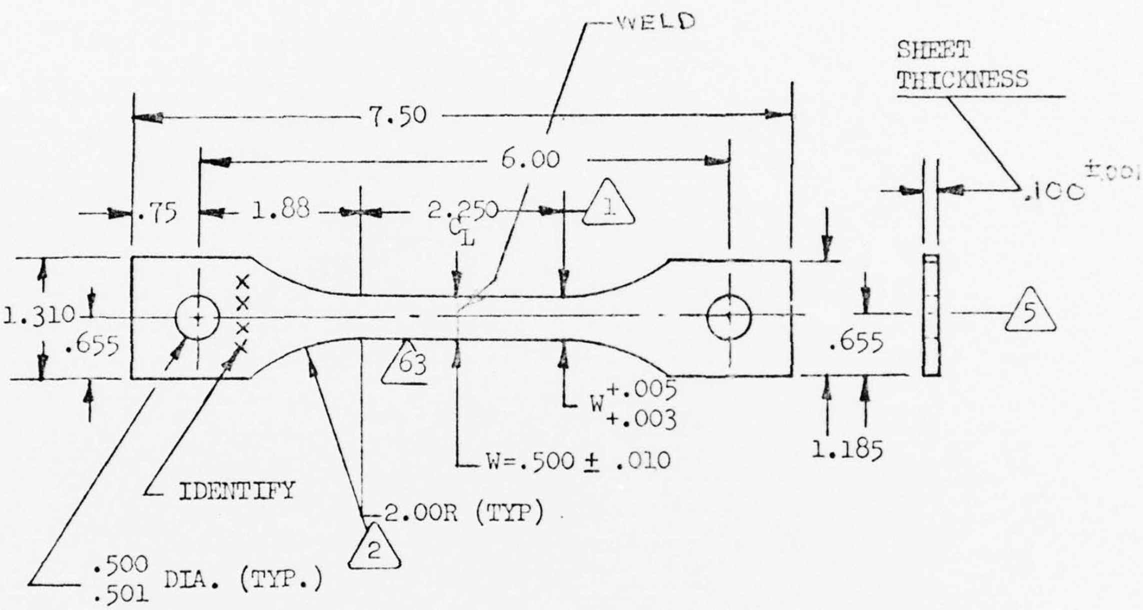
2. NO MISMATCH ALLOWED

3.

4. USE FOR ELEVATED TEMPERATURE

5. SYMMETRICAL TOLERANCE ±.001

FIG. 7-3 - TENSION COUPON - 1 INCH GAGE LENGTH



TENSION COUPON - 2 INCH GAGE LENGTH - SHEET

NOTE: 1 DIMENSION AT ENDS OF THIS GAGE LENGTH MUST BE LARGER BY +.003 TO +.005 INCHES THAN THE W = .500 ±.010 INCHES AT CENTERLINE. RADIUS TAPER FROM ENDS TO CENTERLINE REQUIRED.

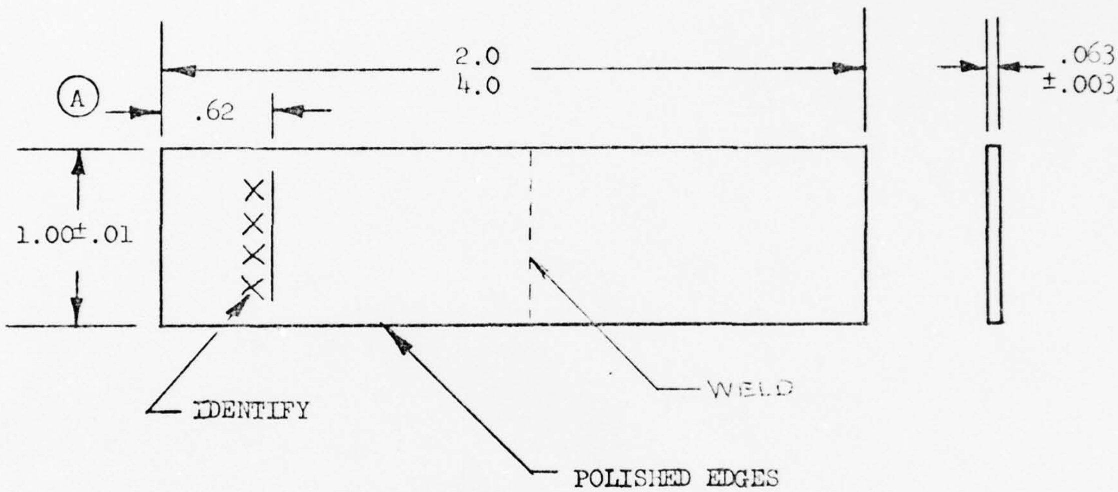
2 NO MISMATCH ALLOWED.

3. USE FOR ELEVATED TEMPERATURE TESTS

4. LEAVE ALL EDGES SHARP

5 SYMMETRICAL TOLERANCE ±.001

FIG. 7-4 - TENSION COUPON - 2 INCH GAGE LENGTH



BRAKE BEND TEST COUPON FOR BAR, EXTRUSION, & FORGINGS

NOTE: 1. HOLD 125 RMS FINISH

FIG. 7-5 - BRAKE BEND TEST COUPON FOR BAR, EXTRUSION, & FORGINGS

AD-A041 284 LOCKHEED-CALIFORNIA CO BURBANK F/G 11/4
LOCKALLOY BE-38AL MATERIAL CHARACTERIZATION, 1976 YEAR-END REPO--ETC(U)
MAY 77 J F SULLIVAN, A C HARAMIS

UNCLASSIFIED LR-28051 NL

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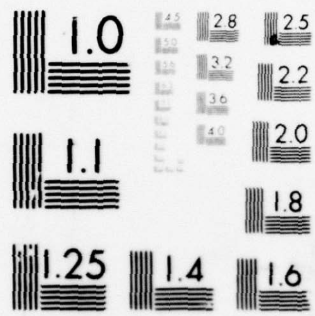
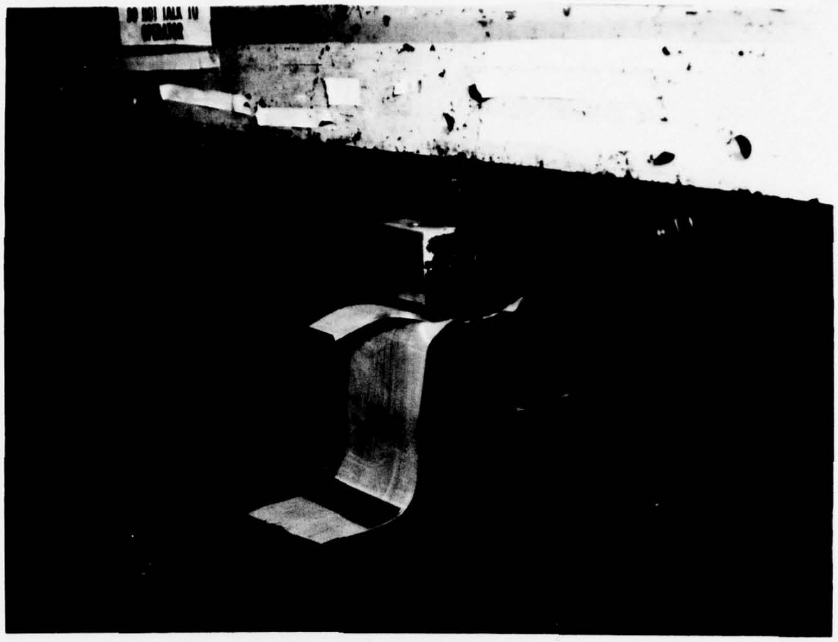
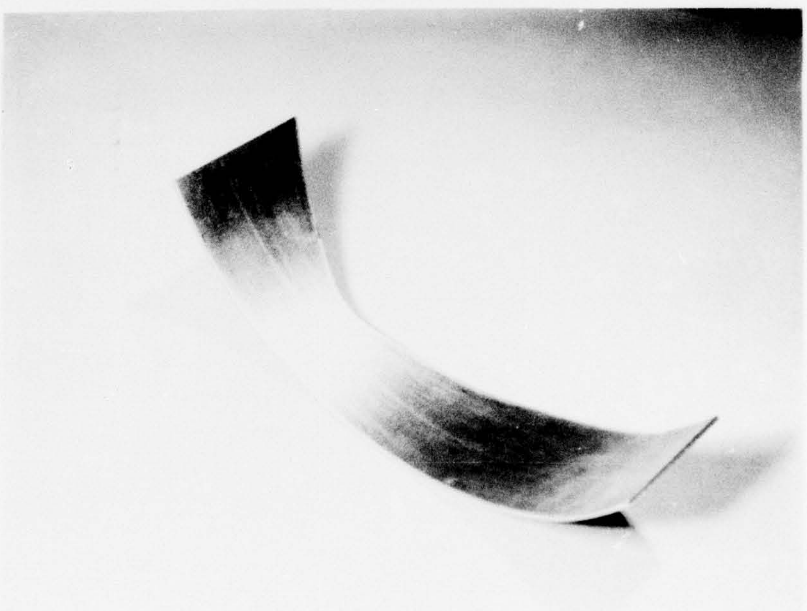


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A



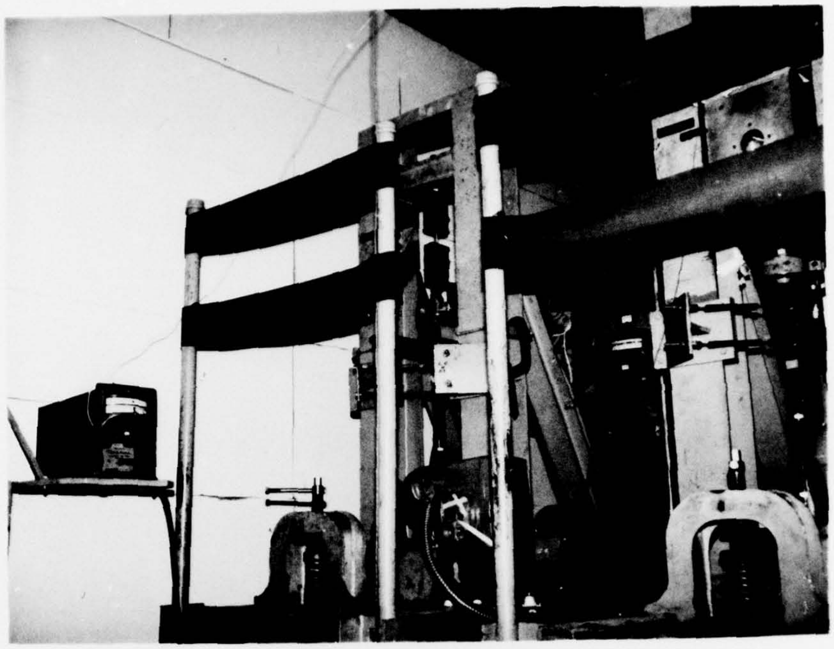
75-5172-2

Fig. 7-6 - Typical Set-Up of Room Temperature Bend Test At R/t of 15 in Power Brake.



77-5037-2

Fig. 7-7 - Roll Formed Weldment ($7\frac{1}{2}$ Inch Radius). Note Visible Weld Line Along.



75-5402-4

Fig. 7-8 - Lockheed Designed and Built 10,000 lb.
Resonant Type Fatigue Machine.

75-5402-3

Fig. 7-9 - Close-Up View of Specimen Installed
In Grips Ready for Fatigue Test at Room Temperature.

WELD TEST RESULTS

Test data from tensile testing welded coupons is compared to the tensile properties of the as-received remnants of Be-38Al. For the 600°F part of the test, the remnant as-received tensile properties were determined by factoring the material properties at room temperature. The factor was calculated by comparing existing data on Be-38Al at room temperature and 600°F. Table 7-III lists the complete tensile test data.

Data for welded coupon bend testing including data on an as-received remnant for comparison purposes is shown in Table 7-IV. View of the welded coupons after the bend test is shown in Figure 7-10.

The roll formed welded remnant is shown in Figure 7-7. Close inspection of the photo will show some porosity voids near the ends of the weld joint. The weld joint in general appeared to be good and showed no degradation due to the roll forming.

Fatigue test data for room temperature and 600°F is shown in Table 7-V. For comparison purposes, fatigue test data is included for samples of as-received Be-38Al .150 thick with $K_t = 3$.

TABLE 7-III. COMPARISON OF Be-38A1 WELDED COUPON TENSILE DATA TO "AS-RECEIVED" MATERIAL

Be-38A1 AS-RECEIVED					WELDED TEST COUPON					%			
SHEET (2) NO. (AVE)	F_{tu} ksi	F_{ty} ksi	e %	E X 10^3	PANEL NO.	F_{tu} ksi	F_{ty} ksi	e %	E X 10^3	F_{tu}	F_{ty}	e	F
ROOM TEMP.													
HC-161-4	53.1	39.2	9.3	27.8		47.3	34.9	6	25.4				
HC-227-1	50.9	36.1	9.3	28.8	#1	48.0	35.4	7	22.9				
						47.5	35.2	6	26.0				
AVE	52.0	37.6	9.3	28.3		47.6	35.2	6	24.8	91.7	94.1	67.7	87.9
HC-161-1	52.5	39.5	8.7	30.0		46.5	36.4	5	24.3				
HC-227-4	53.2	38.0	10.2	34.7	#2	42.8	36.1	4	24.8				
						46.7	36.1	4	26.5				
AVE	52.8	38.8	9.5	32.2		45.3	36.2	4.3	25.2	85.8	93.3	45.3	78.3
HC-137-4	53.0	37.6	8	28.9		41.4	38.5	2	26.3				
HC-137-4	53.0	37.6	8	28.9	#4	42.5	38.2	2	26.4				
						41.8	37.8	2	26.6				
AVE	53.0	37.6	8	28.9		41.9	38.2	2	26.4	79.0	101.6	25	91.3
600°F													
HC-161-4	24.6	24.3	8.3	19.0		22.5	20.5	1.5	18.1				
HC-227-1	25.0	23.4	9.7	21.8	#1	22.7	19.8	1.5	13.4				
						23.0	20.7	1.5	21.9				
AVE	24.8	23.8	8.9	20.4		22.7	20.3	1.5	17.8	91.5	85.3	16	87.2

TABLE 7-IV. RESULTS OF BEND TEST.
WELDED Be-38Al COUPONS (.063)
COMPARED WITH AS-RECEIVED MATERIAL SPECIMEN

SPECIMEN ID	CONDITION	RADIUS (R)	THICKNESS (t)	$\frac{R}{t}$	RESULTS
TH-1-7	WELDED	.75	.063	12	FAILED
TH-1-8	WELDED	1.00	.063	16	FAILED
TH-1-9	WELDED	1.25	.063	20	FAILED
*	AS-RECEIVED	-	.150	15	NO FAILURE

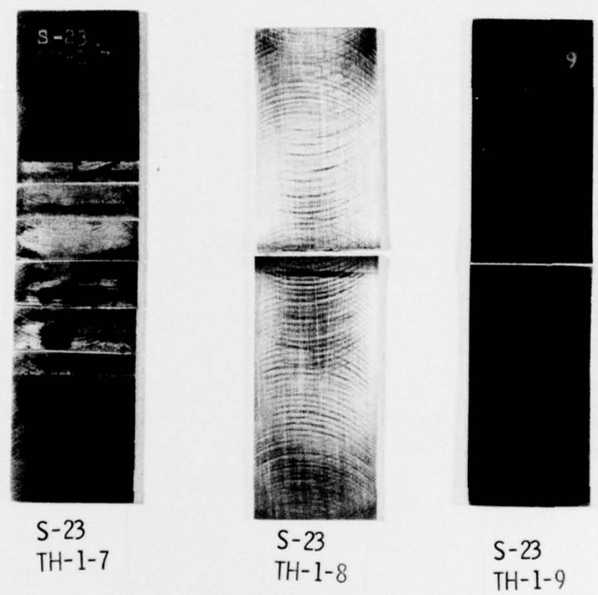
* PREVIOUS TEST RESULTS

TABLE 7-V. FATIGUE TEST DATA
COMPARING .100 THICK WELDED
Be-38Al COUPONS WITH AS-RECEIVED
MATERIAL SPECIMEN $K_t = 3$.

	SPECIMEN ID	CONDITION	TEST TEMP. °F	MAXIMUM STRESS ksi	CYCLES TO FAILURE N
	TH-2-5	WELDED COUPON	ROOM	20.0	7,359,295
	TH-2-4	WELDED COUPON	ROOM	15.0	11,938,680 N.F.
	TH-2-6	WELDED COUPON	ROOM	15.0	10,003,500 N.F.
*	3NF-27	AS-RECEIVED K_t=3	ROOM	15.0	10^7 N.F.
	TH-2-8	WELDED COUPON	600	15.0	671,660
	TH-2-9	WELDED COUPON	600	12.5	5,776,600
	TH-2-7	WELDED COUPON	600	10.0	11,719,030 N.F.
*	3NF-5L	AS-RECEIVED K_t=3 (.150 THICK)	600	10.0	10^7 N.F.

* PREVIOUS TEST RESULTS

N.F. = NO FAILURE



77-5037-1

Fig. 7-10 - Bend Specimens, Room Temp.

ID NO.	FORMING RADIUS	
TH-1-7	.75 IN.	(ALL FAILED)
TH-1-8	1.00 IN.	
TH-1-9	1.25 IN.	

SECTION 8

STRESS-CORROSION TESTS

OBJECT

To determine susceptability to stress-corrosion cracking of Be-38Al Lockalloy material in a 3.5% salt environment.

SUMMARY

Lockalloy test specimens under stress were alternately immersed in a 3.5% NaCl solution for ten minutes and allowed to air dry for 50 minutes. This cycle was repeated for 30 days. The surface of all six (6) coupons tested showed evidence of pitting and discoloration, but none of the specimens failed.

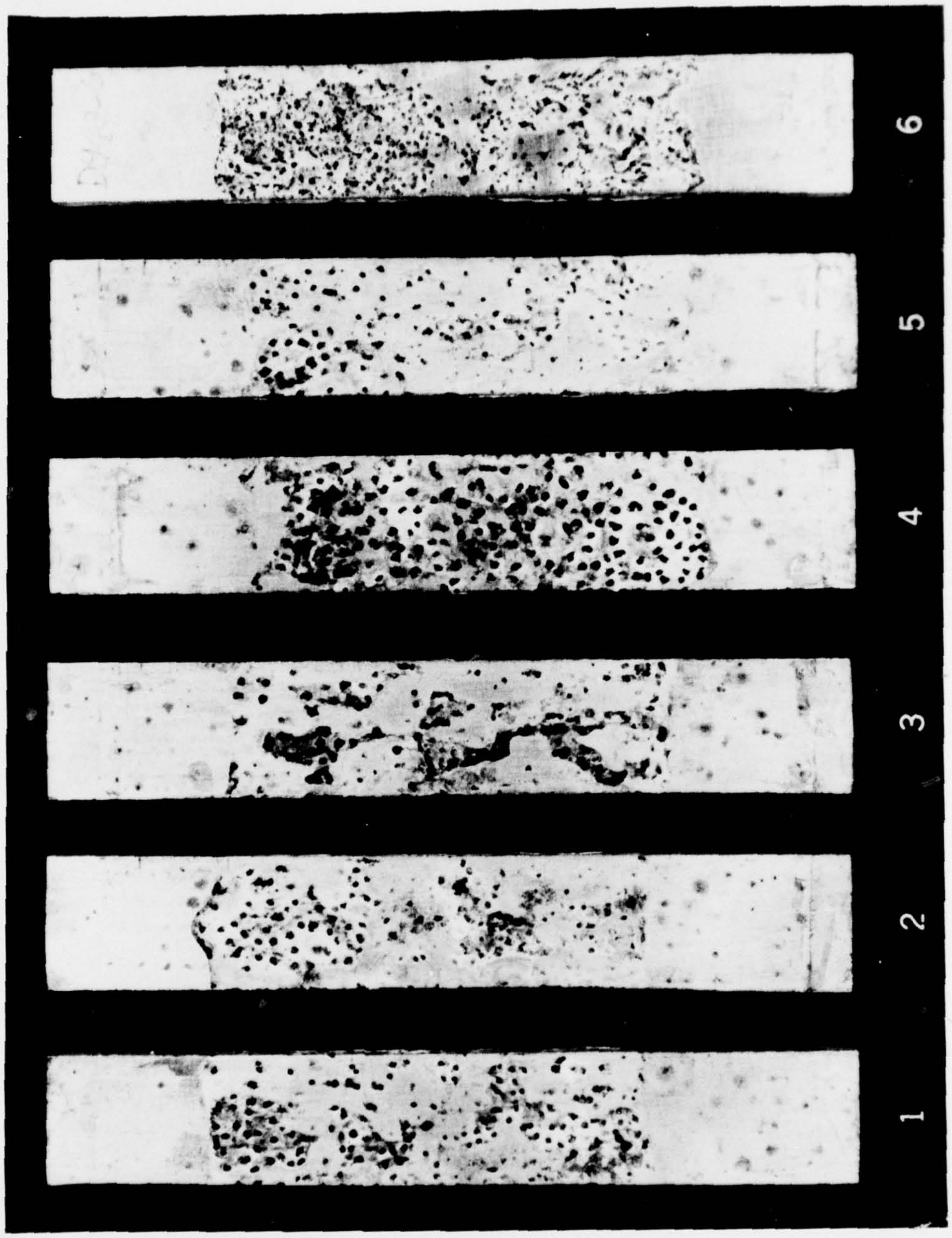
TEST PROCEDURE

Stress-corrosion tests were conducted according to standard ASTM G44-75 practices. The test was performed on six (6) Be-38Al Lockalloy specimens. The dimensions of the specimens were .69 x 3.96 x .145 inches in a transverse direction. The coupons were placed in a "C" frame fixture and stressed to the values shown below:

Specimen No.	Stress K_{si}	Deflection Inch
D 940-1	35	0.018
D 940-2	35	0.018
D 940-3	25	0.013
D 940-4	25	0.013
D 940-5	15	0.0075
D 940-6	15	0.0075

The fixture and ends of the specimens were coated with plastic to prevent dissimilar metal corrosion. The specimens were then immersed in a 3.5% NaCl solution for 10 minutes and allowed to air dry for 50 minutes. This cycle was repeated for 30 days. No failures or evidence of stress corrosion cracking were reported during the test.

At the end of the test, the specimens were removed from the fixtures, washed with water and dried. The appearance of the stressed side of the coupons after testing is illustrated in figure 8-1 and shows evidence of pitting and discoloration.



77-5020-1

FIG. 8-1 - LOCKALLOY STRESS-CORROSION
TEST SPECIMENS

SECTION 9

NONDESTRUCTIVE TESTING (NDT)

METHODS FOR INSPECTION OF Be-38Al LOCKALLOY

OBJECT

To determine if NDT methods such as, radio-graphic and ultrasonic inspections can be used for detecting inclusions or discontinuities in as-received Lockalloy material.

SUMMARY

To guarantee structural integrity of "as received" Lockalloy material it is recommended to use both ultrasonic and an x-ray inspection techniques. After a criteria has been established and more data is accumulated as to types of inherent material defects, the possibility of inspecting by a single method is conceivable. Production inspection can be accomplished by any of the normal NDT methods to inspect parts after various shop operations.

EVALUATION OF NDT METHODS FOR THE INSPECTION OF LOCKALLOY

Samples of Lockalloy submitted to the NDT Group were evaluated to determine if NDT, as a receiving inspection tool, is capable of detecting minute discontinuities. Additionally, the specimens were evaluated to determine the response to NDT methods for possible production and field inspection applications.

In general Lockalloy responds in the same manner as most other non-ferrous materials. The only exception being the special handing requirements.

The preliminary inspection of a 35-inch x 40-inch x 0.125-inch Lockalloy (Beryllium) panel using radiographic and ultrasonic methods has been completed.

From a radiographic standpoint the detection of more dense inclusions (such as aluminum oxides) is easily achieved. More dense inclusions in the range of 0.005-inch are detectable.

From a standpoint of surface crack detection both penetrant and eddy-current inspection may be used.

Ultrasonic inspection of Lockalloy presents no new problems. The only possible problem would be dependent on the criteria established. Currently, defects of 1/32-inch and larger are readily detectable. The detection of 1/64-inch defects is currently marginal but with further refinement of the ultrasonic beam this size defect will be readily detectable.

Ultrasonic C-scan inspection (using the immersion method and a 10 MH_z transducer focused on the back surface) disclosed numerous areas of acoustic attenuation. The test equipment was calibrated to the standard previously fabricated. Since this standard is not the exact thickness of the test panel, the C-scan indications should be subject to further verification.

An additional ultrasonic reference standard was fabricated to more closely match the material thickness under consideration. A new 6 x 8 x .125-inch plate was inspected utilizing both ultrasonic and radiographic inspection techniques. A previously submitted .125 thick panel was also inspected at this time. Numerous ultrasonic indications were noted on the 6 x 8 panel and previously noted indications were seen on the original panel. These ultrasonic indications did not correlate with radiographic indications.

In an effort to obtain correlation with the ultrasonic indications one of the larger indications was sectioned and examined microscopically. The micros did not show any unusual formations which would explain the ultrasonic indications. Further work will be accomplished in an attempt to improve the inspection process.

The current recommendation for receiving inspection of Lockalloy would be X-ray and ultrasonic. Once a criteria has been established and more data is accumulated as to types of defects inherent in this material, the possibility of inspecting by a single method is conceivable.

Production inspection can be accomplished by any of the normal NDT methods established to inspect parts after various shop operations. Ultrasonic inspection is recommended for bondline applications. This method for bond inspection has been successfully used for approximately 10 years. Like all other applications of ultrasonics the only requirement is an adequate calibration standard containing planned defects and simulating the actual joint to be inspected.